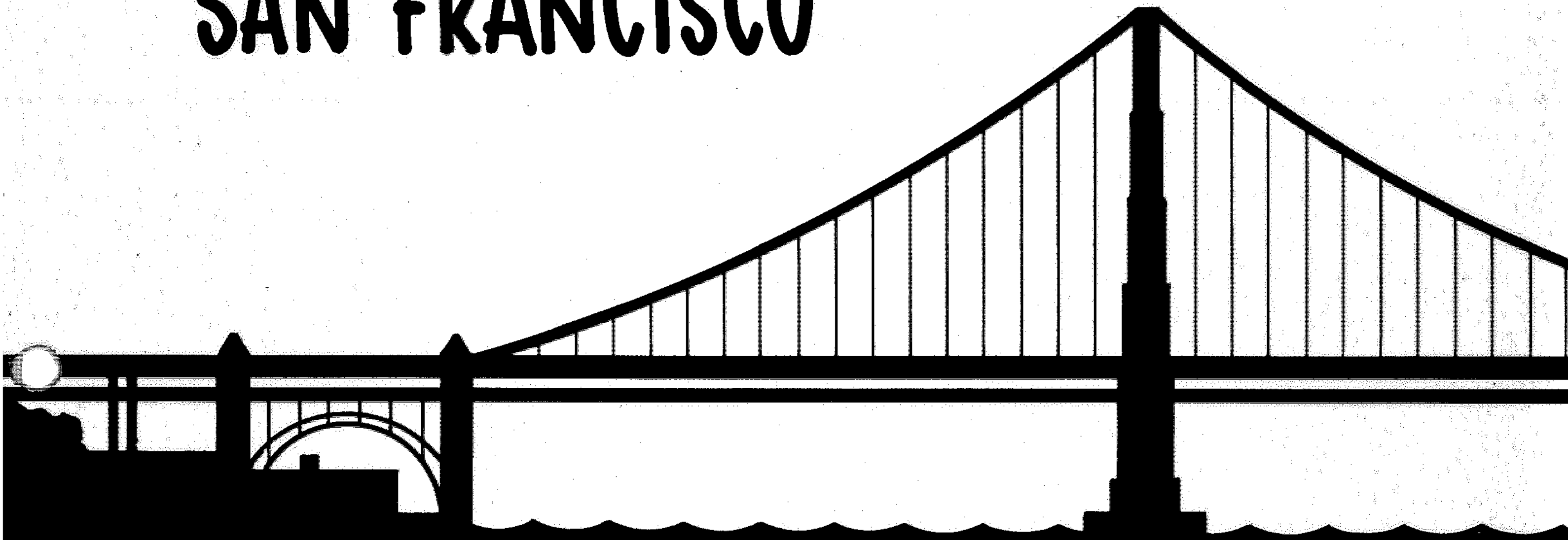
Report for City and County of SAN FRANCISCO



Bayside Overflows

JUNE, 1979

CH2M HILL

TABLE OF CONTENTS

VOLUME ONE - REPORT

I. INTRODUCTION

Background
Scope of Work
Report Organization
Project Staff

II. CONCLUSIONS

Wastefield Dispersion and Dilution
Combined Sewer Overflow Characteristics
Impacts on Water Quality
Impacts on Sediments and Benthos
Impacts on Shellfish
Fish Populations in Overflow Areas
Relation of Combined Sewer Overflows

III. WASTEFIELD DISPERSION AND DILUTION

Introduction
Tides
Winds
Rainfall
Hydrograph
Continuous Dye Releases
Slug Dye Releases
Summary

IV. COMBINED SEWER OVERFLOW CHARACTERISTICS

Introduction
Coliform
Suspended Solids
Salinity
Ammonia
Summary

V. IMPACTS OF COMBINED SEWAGE OVERFLOWS ON WATER QUALITY

Introduction
Salinity
Temperature
Suspended Solids
Dissolved Oxygen
pH
Bacterial Die-off
Coliforms
Summary

VI. IMPACTS OF COMBINED SEWAGE OVERFLOWS ON SEDIMENTS AND BENTHOS

Introduction
Results and Discussion - Sediments
Results and Discussion - Benthic Infauna
Summary

VII. IMPACTS OF COMBINED SEWAGE OVERFLOWS ON SHELLFISH

Introduction
Results
Summary

VIII. FISH POPULATIONS IN OVERFLOW AREAS

Introduction
Results
Summary

IX. RELOCATION OF COMBINED SEWAGE OVERFLOWS

Introduction
Physical Characteristics in San Francisco Bay
Deep Water Outfalls
Shoreline Discharges
Summary

LIST OF TABLES

		Page
I-1	Location of Monitoring Stations	I-5
III-1	Dates of Dye Experiments	III-10
III-2	Tide Chart - Stages and Slacks at Potrero Point	III-11
III-3	Wind Data - San Francisco International Airport	III-13
III-4	Spatial and Temporal Extent of Dilution for the Sunnydale Dye Release	III-16
IV-1	Ammonia Concentration in Combined Sewer Overflows	IV-5
VI-1	Benthic Sediment Chemistry - Means and Standard Deviations	VI-13
VI-2	Sediment Chemistry Data - One Way Analysis of Variance	VI-21
VI-3	Heavy Metals In Sediments Near Islais Creek	VI-27
VI-4	Benthic Invertebrates Species List	VI-28
VI-5	Number of Individuals and Species Per Station	VI-34
VI-6	Ranked Abundances of Benthic Inverte-brate Species	VI-39
VII-1	Tissue Bacterial Levels of Clam Samples	VII-12
VII-2	Trace Metal Concentrations in Depurated and Undepurated Clam Tissue	VII-13
VII-3	Average Levels of Trace Metals in Clam Tissues	VII-14
VII-4	Heavy Metals and Trace Elements in Mussels Collected in San Francisco Bay	VII-15
VII-5	Sediment Chemistry At Shellfish Stations	VII-18
VIII-1	Taxonomic List of Fish Species	VIII-6
VIII-2	Fish Weight and Abundance Summary	VIII-7
VIII-3	Heavy Metal Tissue Levels - English Sole	VIII-8
VIII-4	Heavy Metal Tissue Levels - Staghorn Sculpin	VIII-9
IX-1	Overflow Capacities and Maximum Upstream Water Surface Elevations	IX-10
IX-2	Characteristics of Bay Outfall Alternatives	IX-11
IX-3	Bay Outfall Pumping Alternatives	IX-12
IX-4	Capital Cost Estimates	IX-13
IX-5	Initial Dilution Obtained by Shoreline Surface Discharge	IX-14
IX-6	Advantages and Disadvantages of Relocating Overflow Discharges	IX-15

LIST OF FIGURES

		Page
I-1	Water Quality Stations	I-8
I-2	Benthic, Sediment and Shellfish Stations	I-9
III-1	Daily Rainfall Records	III-17
III-2	Rainfall Records During Water Quality and Dye Activities	III-18
III-3	Overflows Into Islais Creek	III-19
III-4	Overflow From Yosemite and Ingalls Sewers	III-20
III-5	Overflow From The Division Sewer (Channel)	III-21
III-6	Overflow From The Sunnydale Sewer	III-22
III-7	Islais Creek - Dye Dilution Contours	III-23
III-8	Islais Creek - Dilution Profiles	III-24
III-9	Tidal Stage and Wind - Islais Creek Dye Release	III-26
III-10	Yosemite Overflow - Dye Dilution Contours	III-27
III-11	Yosemite Overflow - Dilution Profile	III-28
III-12	Tidal Stage and Winds - Yosemite Overflow Dye Release	III-29
III-13	Channel Overflow - Dye Dilution Contours	III-30
III-14	Channel Overflow - Dilution Profiles	III-31
III-15	Tidal Stage and Winds - Channel Overflow Dye Release	III-33
III-16	Shore Stations for Sunnydale Continuous Dye Release	III-34
III-17	Sunnydale Dye Release	III-35
III-18	First Slug Dye Release at Channel	III-36
III-19	Second Slug Dye Release at Channel	III-37
III-20	Islais Creek Dye Release	III-38
V-1	Channel Creek Transect - Water Quality Profiles	V-9
V-2	Islais Creek Transect	V-11
V-3	Yosemite Outfall Area Transect - Water Quality Profiles	V-13
V-4	Total Coliform Levels in Islais and Channel Creek	V-14
V-5	Total Coliforms, Storm 3, On 27 March @ 1100 Hrs.	V-15
V-6	Total Coliforms, Storm 3, On 28 March @ 1800 Hrs.	V-16
V-7	Total Coliforms, End of Storm 3, On 30 March @ 1400 Hrs.	V-17
VI-1	Benthic Infauna and Sediment Sampling Stations	VI-40
VI-2	Benthic Sediments - Particle Size Distribution	VI-41

		Page
VI-3	Benthic Sediments - Total Sulfides and Grease and Oil	VI-43
VI-4	Cadmium and Mercury Concentrations in Benthic Sediments	VI-44
VI-5	Lead, Copper, and Zinc Concentrations in Benthic Sediments	VI-46
VI-6	Silver and Arsenic Concentrations in Benthic Sediments	VI-48
VI-7	Chromium and Nickel Concentrations in Benthic Sediments	VI-50
VI-8	Total Biomass - Sampling I	VI-52
VI-9	Total Biomass - Sampling II	VI-53
VI-10	Total Biomass - Sampling III	VI-54
VI-11	Total Biomass - Sampling IV	VI-55
VI-12	Total Biomass - Sampling V	VI-56
VI-13	Number of Benthic Infaunal Species	VI-57
VI-14	Number of Benthic Infaunal Species	VI-58
VI-15	Benthic Infaunal Species Diversity	VI-59
VII-1	Candlestick Cove, Clam Tissue Fecal Coliforms - July 1978 Through April 1979	VII-19
VIII-1	Fish Trawl Locations	VIII-10
VIII-2	Fish Length Frequency Distributions	VIII-11
IX-1	Bay Outfall Alternatives Location	IX-16
IX-2	Density Profile - Bay Outfall Location	IX-17
IX-3	Density Profile - Bay Outfall Location	IX-18
IX-4	Density Profile - Bay Outfall Location	IX-19
IX-5	Density Profile - Bay Outfall Location	IX-20
IX-6	Channel Street Outfall Extension	IX-21
IX-7	Islais Creek Outfall Extension	IX-22
IX-8	Yosemite Outfall Extension	IX-23
IX-9	Northpoint Outfall Extension	IX-24

I. INTRODUCTION

BACKGROUND

San Francisco has a combined sewer system. When rainfall intensity exceeds approximately 2/100 of an inch per hour, excess combined sewage flows are discharged untreated into the Bay and ocean at 39 locations surrounding the City. During an average rainfall year, approximately 80 untreated overflows will occur.

San Francisco is implementing an extensive wastewater management program to upgrade storage, treatment and transport facilities to significantly reduce the number of untreated overflows. The configuration and sizing of the various wastewater program elements on the Bay side of the City have not been finalized pending a decision by the Regional Water Quality Control Board (RWQCB) with respect to the number of allowable untreated overflows.

The City and County of San Francisco (CCSF) has contracted with CH2M HILL to quantify the impacts on San Francisco Bay of untreated combined sewage overflows (CSO's). The findings from this study will be utilized by the RWQCB and CCSF in establishing equitable discharge criteria.

SCOPE OF WORK

The objective of this study is to quantify the impacts on San Francisco Bay associated with untreated combined sewage overflows. In general, the project involved review of existing data, development and execution of an extensive monitoring program, interpretation of results and finally, preparation of this report. More specifically, the following activities were undertaken:

- Literature search of existing reports and papers to quantify the impacts of combined sewage overflows on San Francisco Bay

- Collected offshore and nearshore grab samples before, during and after three overflow events to determine water quality characteristics. There were 15 offshore stations and eight nearshore stations (Figure I-1 and Table I-1). On the first 2 days of the overflow event, samples were collected at each offshore and nearshore station every quarter tidal cycle at slack water. On the following 3 days, samples were collected at one high and one low slack water condition. Each water sample was analyzed for total and fecal coliforms, suspended solids and conductivity. When water depths were greater than 15 feet, samples were collected 2 feet below the surface and at 6 feet above the bottom. Vertical profiles for pH, dissolved oxygen, temperature, conductivity and salinity were also obtained at these stations. When water depths were less than 15 feet, samples were collected 2 feet below the surface.

- Collected combined sewage overflow samples during three overflow events to determine waste characteristics. Automatic samplers were utilized and set up to composite hourly subsamples into one sample every tidal cycle. There were six stations sampled (Figure I-1 and Table I-1). Each waste sample was analyzed for total and fecal coliforms, suspended solids and conductivity. During the last storm event, ammonia nitrogen measurements were obtained at three major overflow structures.

- Continuously released Rhodamine dye into the sewers upstream of four overflow structures to measure overflow quantity and to determine the dilution and dispersion of the overflowing wastewater as it moved away from the discharge structure. The horizontal and vertical extent of the dye field was determined. Dye was released in the Division, Marin, Selby and Sunnydale overflow systems (Table I-1 and Figure I-1).

- Released a slug of Rhodamine dye at the mouths of China Basin and Islais Creek and adjacent to the Sunnydale overflow structure during dry weather. These release points were selected to indicate the dilution and dispersion patterns which would occur if the overflows were extended offshore. The dye patch adjacent to the Sunnydale overflow was traced, using aerial photography.

- Collected benthic samples at 16 stations (Figure I-2 and Table I-1) before and after each of the three overflow events. Benthic invertebrates were identified by species and enumerated. The total weight of major phylogenetic groups was determined.

- Collected sediment samples at the 16 benthic stations before and after each of the three overflow events. Each sample was analyzed for grain size distribution, total organic carbon, trace elements, sulfide, grease, percent hydrocarbons and total identifiable chlorinated hydrocarbons (TICH).

- Collected shellfish (primarily *Tapes japonica*) at seven stations (Figure I-2 and Table I-1) before and after each of the three overflow events. The clams were analyzed for total and fecal coliform, trace elements and TICH.

- Conducted a bacterial reduction study which consisted of bag tests at four dilutions of wastewater to determine the die-off rate of total and fecal coliforms.

- Measured total and fecal coliforms in the sediment at Candlestick Cove at set intervals during a storm event and for 20 days thereafter. Bacterial decay rates were obtained.

- Conducted bottom trawls for the purpose of identifying the species of fin fish that reside near the wet weather overflow structures. Each catch was enumerated by species and size class distribution. Liver to body weight ratios were determined. In addition, trace element tissue analyses were performed.

- Determined outfall configurations and feasibility level cost estimates for extending the combined sewage overflows into the Bay adjacent to the following overflows: North Point, Channel, Islais, and Yosemite.

- Evaluated the detrimental and benefical impacts of relocating existing overflows in the dead end sloughs to deeper waters in the Bay or to the Bay shoreline.

- Prepared progress reports, an interim and final report and assisted CCSF at meetings with regulatory agencies.

REPORT ORGANIZATION

This report is organized to present in sequence the wastefield dispersion and dilution, combined sewage overflow characteristics, impacts of combined sewage overflows on water quality, sediments, benthos and shellfish, fish populations in overflow areas and the detrimental and beneficial impacts of relocating the existing overflows.

The text of the report is intended to summarize in a succinct manner the pertinent data, analyses and conclusions. Data, collected in the monitoring program, has been tabulated in Volume Two, Appendices A through I.

PROJECT STAFF

The following people have participated in the preparation of the information presented in this report:

Principal in Charge	William O'Leary
Project Manager	Richard Meighan
Deputy Project Manager	Dr. Roderick Hoffman
Professional Staff	Marilyn Bailey Thomas Coyner Craig Crouch Marilyn Dienst Peter Dygert Jane Dykzeul John Johnson Phillip Kohne Henry Lin Susan McCormick Jerri Romm Kent Rozelle Joseph Scott Michael Smirnov Dr. Noel Williams David Wilson
Technical Staff	Mary Byrne Derek Davis Beverly Epstein Brian Eriksen John Hedges Jane Joyce Jess Lapid Paul Pouliot Nancy Rickerd Jay Williams
Principal Subconsultants	EMRI Inc. LFE Environmental Labs
Special Consultants	Dr. Norman Brooks Dr. Robert Koh Dr. James Roth Dr. Steve Strand PBQ&D Inc. Robert Ishida Ronald Ashwin

TABLE I-1
LOCATION OF MONITORING STATIONS

Offshore

B1	1 mile north of Oyster Pt. Breakwater, 1/2 mile northeast of landfill at Sierra Point and 1 mile east of Candlestick Causeway
B2	3/4 mile east of Candlestick Point, 1/4 mile south of southernmost pier
B3	1/2 mile northeast of Candlestick Point, 100 yards south of pier to north
B4	160 yards south of White fuel tank, 150 yards east of piling on chart
B5	1/4 mile southeast of north end of Hunter's Point; 3/4 mile northeast of southern corner of Hunter's Point
B5A	1/4 mile due east of B5
B6	25 yards north of buoy outside Islais Creek
B7	Mouth of Islais Creek, parallel with the end of Army Street Terminal
B7A	1/8 mile due east of B-7
B7B	1/4 mile due east of B-7
B8	1/8 mile due east of Central Basin easternmost drydock
B9	1/16 mile from end of Pier 46; 1/8 mile from end of Pier 48
B10	50 yards due south of mid-length along Pier 46
B10A	1/8 mile due east of B-9
B11	1/8 mile due east of Pier 32

Nearshore

S1	1/3 mile south of Brisbane Lagoon Entrance
A1	Brisbane Lagoon Entrance
S2	3/4 mile north of Brisbane Lagoon Entrance
S3	600 feet south of Sunnydale Overflow
S5	Pier at the end of Rankin Street and Islais Creek
S6	Third Street Bridge and Islais Creek
S7	Floating pier in China Basin (houseboats)
S8	Third Street Bridge and China Basin

TABLE I-1
(Continued)

Combined Sewage Overflows

A2	Sunnydale Overflow
A3	Yosemite Overflow
S4	Griffith Overflow
A4	Selby Overflow
A5	Marin Overflow
A6	Division Overflow

Benthic and Sediment

1	Inshore along Highway 101 causeway; Mini-Ranger,* (N)2590:(S)2290
2	Offshore along Highway 101 causeway, Mini-Ranger,* (N)3122:(S)2053
3	Offshore along 101; Mini-Ranger,* (N)2435:(S)2760
4	Offshore along 101; Mini-Ranger,* (N)1747:(S)3497
5	1/2 mile due south of Candlestick Pt.; Mini-Ranger,* (N)1907:(S)4088
6	Same as Water-Quality Station B-4; Mini-Ranger,* (N)2490:(S)5688
7	Same as Water-Quality B-2; Mini-Ranger,* (N)2913:(S)5160
8	Off Hunter's Point, 1/4 mile from end of northern pier, 3/4 mile from end of southern pier (east-most structure)
9	25 yards north of buoy outside Islais Creek; Water Qual. B-6
10	Islais Creek, between the Stateline Pier on north (100 feet) and the corner of the first pier on south shore
11	Islais Creek; 25 yards south of the west end of Stateline pier
12	Islais Creek; center of channel, even with the derrick and small house on north side of Islais
13	Same as Water Quality B-9
14	Channel Creek; 50 yards off south shore perpendicular to green house and the end of rip-rap
15	Channel Creek; 20 yards off corner of first south pier past second bridge
16	Channel Creek; 20 yards east of wet weather overflow structure on north shore, mid-channel

TABLE I-1
(Continued)

Shellfish

A	West Bank of Brisbane Lagoon - 1,800 feet from southern end
B	North bank of Brisbane Lagoon - in middle
C	1,100 feet south of Brisbane Lagoon Entrance
D	1,600 feet north of Brisbane Lagoon Entrance
E	Candlestick Cove - 300 feet NE of Sunnydale overflow
F	Candlestick Point - South side, 2,000 feet east of pier
G	300 feet east of Griffith overflow
H	Warm Water Cover - SW corner

*Exact Mini-Ranger shore transponder station locations may be obtained from CH2M HILL, INC.; the northern station was on the Sunnydale Overflow structure and the southern station on the southeastern corner of Oyster Point. Distance values for Mini-Ranger coordinates are given in meters.

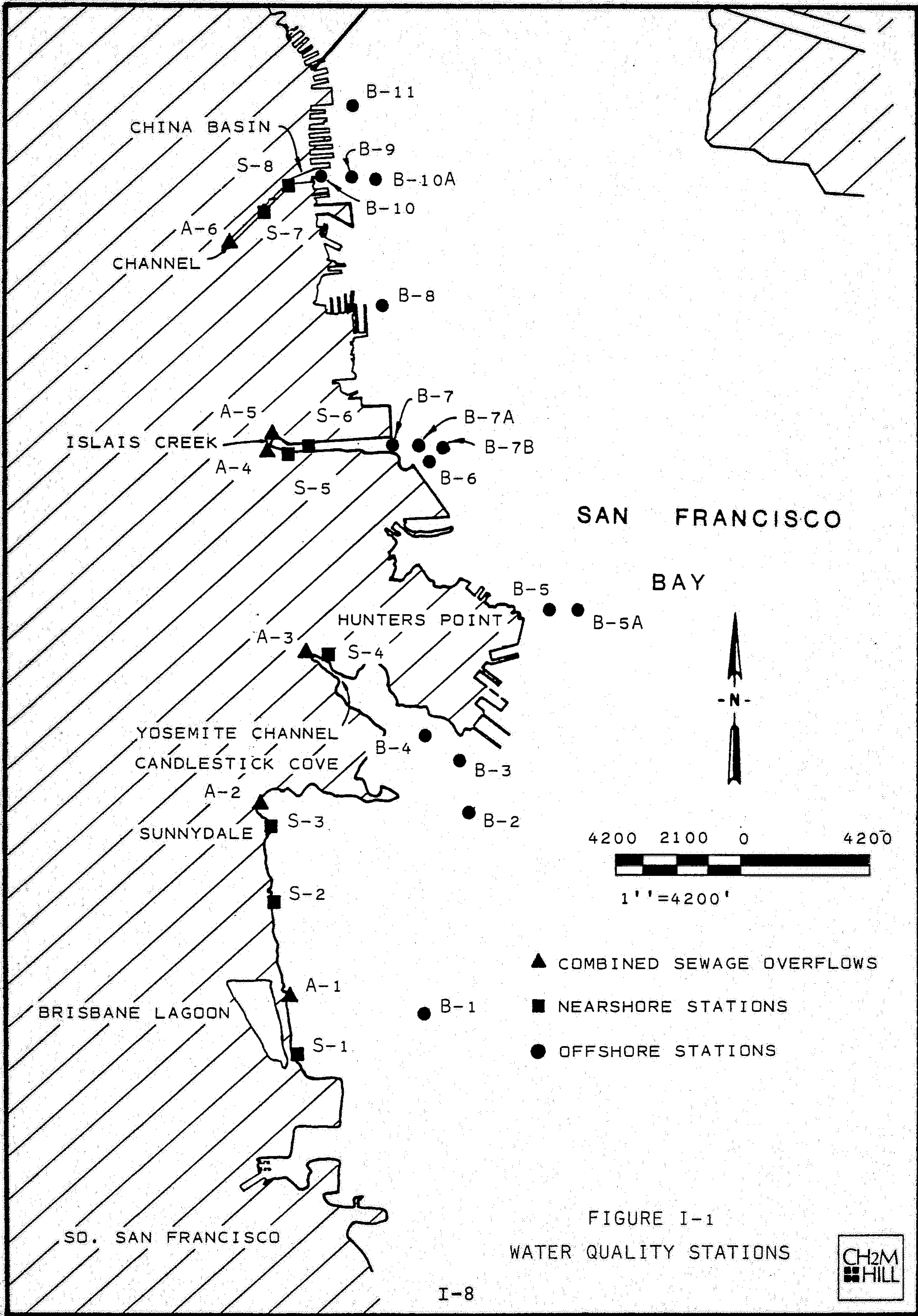


FIGURE I-1
WATER QUALITY STATIONS

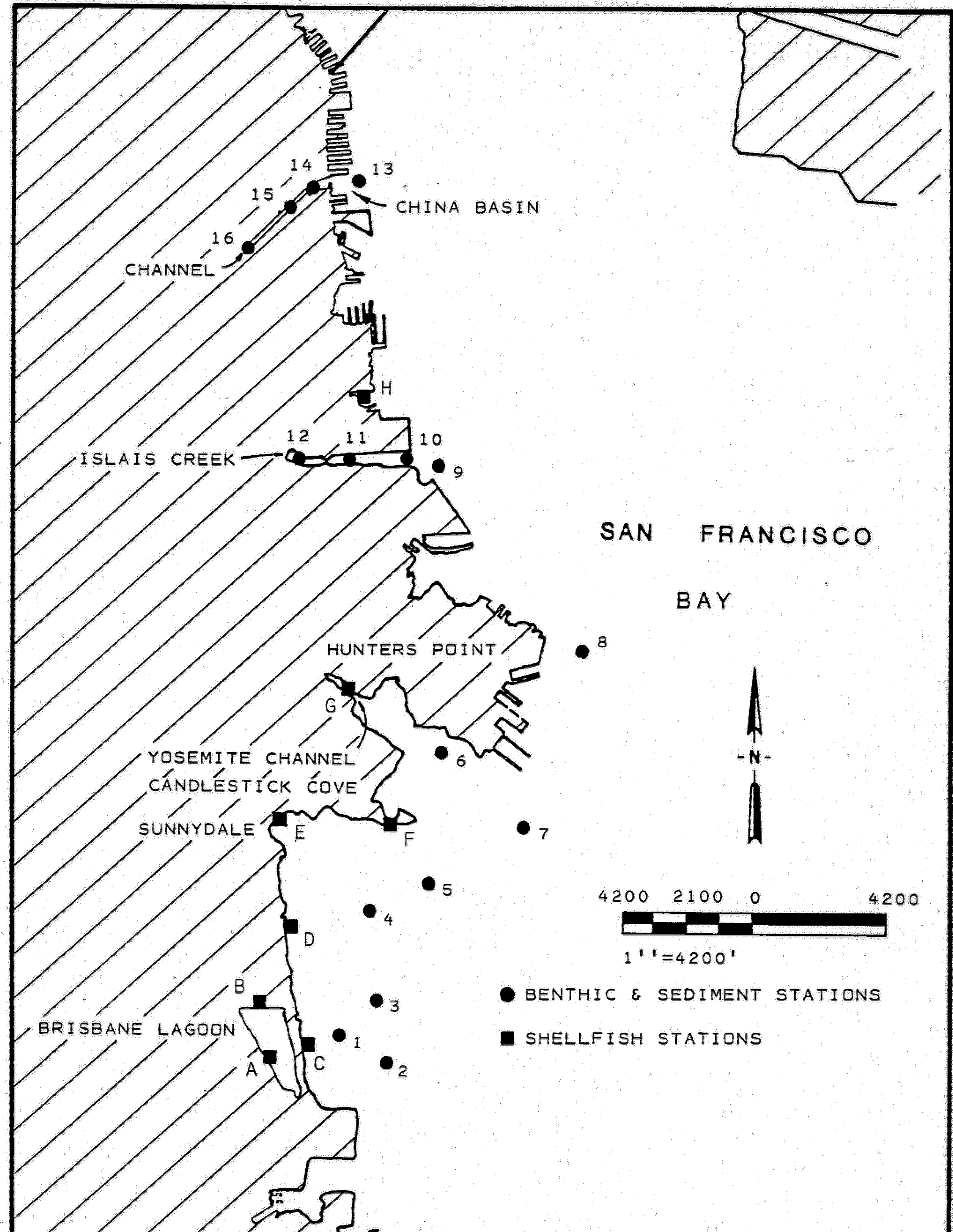


FIGURE I-2

BENTHIC, SEDIMENT AND SHELLFISH STATIONS

II. CONCLUSIONS

WASTEFIELD DISPERSION AND DILUTION

A 10:1 dilution of the dye fields near the Islais, Channel and Yosemite overflows was reached near or before the bayward end of each area. Wastefields were highly stratified within confined receiving water areas (usually within the upper 3 feet). The bayward extent of these three overflow dye fields was restricted to at or within the pierline presumably due to the rapid dilution and dispersion by open bay currents and turbulence. Dye field movement in the Sunnydale C.S.O. receiving area was primarily eastward on ebb tide. No southern movement to the Brisbane Lagoon culverts was noted. All dye fields were undetectable within 11 to 14 hours after release.

The movement of the slug dye releases at the mouth of Channel was due primarily to the tidal currents. The dye released at the beginning of ebb tide moved rapidly north and disappeared as it passed under the Bay Bridge. The Channel release during flood tide moved a dilute section of dye upstream to within 500 feet of the overflow structure. Both of these patches moved against the direction of the prevailing wind.

The dye slug at Islais Creek moved rapidly south with the incoming tide and the northerly wind. The patch moved as a unit with little dilution until it reached Hunter's Point where it was quickly diluted and dispersed.

The slug release at Sunnydale moved very slowly and was affected by both wind and tide. The patch at first drifted south to within 1 mile of the Brisbane Lagoon entrance and then turned eastward where it was dispersed beyond Candlestick Point.

COMBINED SEWER OVERFLOW CHARACTERISTICS

Six-hour composite samples were collected to characterize combined sewer overflows. The salinity of the combined sewer overflows was less than 1 ppt. Average suspended solids levels were less than 100 mg/l. There was inconclusive evidence of a suspended solids flushing peak due to the manner in which samples were composited. Coliform values ranged from 10^3 to 10^8 MPN/100 ml. Most total coliform values at the overflow structures were roughly 10^6 MPN/100 ml.

IMPACTS ON WATER QUALITY

Impacts on physical water quality (temperature, dissolved oxygen, pH, salinity and suspended solids) were temporary and confined to nearshore areas. There were strong salinity gradients within the top 3 to 6 feet in the channels of Islais Creek and Channel with gradual gradients present at the pier line. The effects of the overflows on dissolved oxygen levels were usually minimal. Dissolved oxygen concentrations in the wastefield were typically between 70 and 90 percent of saturation. The dissolved oxygen levels of the offshore stations were unaffected. Combined sewer overflows usually had a minor impact on pH and temperature. Suspended solids concentrations at the offshore and near-shore stations were not directly related to C.S.O.'s.

Dumping of industrial effluents temporarily altered oxygen and pH values significantly. The coliform levels appeared to be directly related to the times of overflows. When an overflow occurred, the coliform levels near the overflow structures jumped several orders of magnitude above back-ground levels. After an extended overflow the offshore stations were also one order of magnitude above background. Within 2 days the offshore stations returned to background levels. Coliform levels inside the channels returned to normal within 3½ days. The T_{90} values in the channels, including natural die-off, physical dilution and sedimentation, was about 24 hours. The T_{90} value in the bag experiments was 36 hours.

IMPACTS ON SEDIMENT AND BENTHOS

The sediment results indicate that the C.S.O.'s are significant point sources for the introduction of metals, oil and grease, and petroleum products (percent hydrocarbons), into the nearshore marine environment; and that there is a long-term cumulative effect localized near the points of discharge. The water movement and tidal currents flushing are important in reducing the concentration of the overflow discharge parameters that may accumulate in the sediments.

Benthic infauna results do not show any definitive decrease in biomass, number of species, or number of individual organisms through the duration of the study or as a result of any single overflow event. Numerically abundant benthic species from the stations in closest proximity to the C.S.O.'s (Islais and Channel Creeks) had only three species in common and both regions had minimal species overlap with the abundant species from stations away from the C.S.O.'s. Benthic stations in intermediate proximity to the C.S.O.'s had the highest species diversity and biomass which reflects the increased availability of organic materials.

IMPACTS ON SHELLFISH

As a result of overflows, statistically significant increases in shellfish fecal coliform levels occurred within 300 feet of overflow structures. No changes attributable to C.S.O. occurred in other shellfish beds although their fecal coliform content also increased. Shellfish have the ability to purge themselves of bacteria and viruses. This is an efficient process, with low levels reached within 72-96 hours or less once the source of pollution is removed. Historical data reveals that shellfish standards are exceeded by all beds in the study area during the rainy season. The evidence indicates that removal of C.S.O.'s would not make shellfish harvestable.

No evidence was found for C.S.O. having any detectable additional effect on shellfish heavy metal and chlorinated hydrocarbon content.

Most chlorinated hydrocarbon levels in shellfish tissue were below detectable limits.

Sediment characteristics were unique at each shellfish station. There does not appear to be a relationship between sediment characteristics and combined sewer overflows.

FISH POPULATIONS IN OVERFLOW AREAS

There was a great difference in abundance and species composition between the two stations inside Islais Creek and Channel and the four remaining stations (outside Islais Creek and Channel and near Sunnydale and Yosemite). The two stations had very few species and had few individuals. This was attributed to the characteristics of the bottom habitat which is suboptimal for most species. The bottom fish at the four outer stations do not appear to be affected by the wastewater overflow. No abnormalities were observed on any of the fish collected in this study. There was no evidence indicating that combined sewer overflows had a direct impact on heavy metal concentrations in fish tissues.

RELOCATION OF COMBINED SEWER OVERFLOWS

The discharge requirements of 10:1 or 5:1 dilution can be met with a deepwater outfall or a Bay shoreline surface discharge. With a deepwater outfall, the wastewater plume will be submerged and would have a greater probability of becoming trapped in the South Bay due to the overall poor net flushing capacity. The negative water quality impacts to the South Bay, the risk of physical damage due to ship's anchors, and the high construction costs make the extended deep water outfall solution unfeasible.

Relocation of the existing overflow discharges to the Bay shoreline would improve the water quality in sloughs marginally. The dilution requirements could be met if high discharge velocities are provided. The shoreline surface discharges after relocation would create some negative water quality impacts around the discharge locations and nearby shorelines, but this impact would be transient and would be rapidly flushed out of the Bay by tidal flushing. It was observed that a portion of the shoreline discharge at Channel was carried back into the dead end slough by tidal action. Transient water quality impacts due to relocated CSO's would be less intense inside the dead end sloughs but would extend over a greater portion of the bay proper. Again, the high construction cost of this solution in comparison to the benefits obtained make this solution unattractive.

III. WASTEFIELD DISPERSION AND DILUTION

INTRODUCTION

A series of dye experiments were conducted during this study to measure combined sewer overflow quantities and to determine the dilution and dispersion of the overflowing wastewater as it moved away from the discharge structure. Rhodamine WT dye was continuously released for a period of time during an overflow event into one of the following five sewer systems: Division, Marin, Selby, Yosemite and Sunnydale. The Division sewer system overflows into Mission Creek (China Basin) at the end of Channel Street. The Marin and Selby sewer systems overflow into the head end of Islais Creek.

In addition to the continuous dye releases, slugs of dye were released at the mouths of China Basin and Islais Creek and adjacent to the Sunnydale overflow structure during dry weather. These release points were selected to indicate the dilution and dispersion patterns which would occur if the overflows were extended offshore. Table III-1 lists the dates when the dye experiments were performed.

TIDES

Table III-2 indicates the daily tides for February and March with the times and heights adjusted to Potrero Point. The tides for each day are given in order of their occurrence starting with the early morning tide. There are usually two high and two low waters each day. On some days only three tides occur with the fourth tide appearing shortly after midnight on the following day.

The column of stage heights shows the elevation above or below mean lower low water (MLLW). The heights are expressed in feet with a minus sign (-) indicating the height is below the datum.

The slack tide column shows the predicted times at which there is no current. This is when the current has stopped moving in a given direction and is about to begin setting in the opposite direction. For example, a slack tide following high water indicates the time the current will reverse and ebb tide will begin. Similarly, the slack tide following low water shows when the flood tide begins.

The discussion of each continuous and slug dye release contains a graph of the tidal cycle for the day involved.

WINDS

Table III-3 contains February and March wind data. The observations were taken at 3-hour intervals at the National Weather Service Office at San Francisco International Airport. The wind data was utilized in analyzing dye field movements.

The wind directions, shown in degrees clockwise from true north, are those from which the wind blows. For example, a direction of 90 is a wind blowing from the east towards the west. An entry of 00 indicates calm. The wind speed is expressed in knots. To convert to miles per hour, multiply knots by 1.15.

RAINFALL

The principal objective of this project was to determine the impact of combined sewer overflows on San Francisco Bay between the Bay Bridge and Sierra Point. Accordingly, most of the project tasks were undertaken during and immediately after major rain events. This section summarizes the rainfall data during February and March 1979, the time period when field activities were performed. Figure III-1 presents daily precipitation values at CCSF rain gauge 24. This gauge is located in the study area near the intersection of 4th and 3rd Streets. Figure III-2 presents hourly precipitation values at the same rain gauge for those periods when the continuous dye experiments and water quality sampling programs were performed.

HYDROGRAPHS

Flow was measured at each of the overflow structures. Several methods of flow determination were attempted. These included a tracer dilution technique, Stevens level recorders, timing the surface velocity of floating objects, and the use of current meters. Of these, the current meter technique was found to give the most reliable results.

At the Islais and Yosemite sites, flows were measured in the sewer system upstream of the overflow structure. For Channel Street and Sunnydale, the flows were measured at the overflow structures.

Hydrographs for the five overflows are shown in Figures III-3 through III-6. Figure III-3 shows the hydrographs at both the Selby and Marin overflows and the combined hydrograph entering Islais Creek. Peak flows were 980, 355, and 1,280 cfs respectively. Figure III-4 shows the combined hydrograph at the Yosemite overflow resulting from the flows in the Ingalls and Yosemite Street sewers. The peak flow was 245 cfs.

The hydrographs for the Channel and Sunnydale Overflows, shown in Figures III-5 and III-6 each indicate two overflow peaks during the same storm. Dye was released during both peaks at each overflow. The tide gates were closed during the 3- to 4-hour period between overflows as rainfall was minimal and the tidal stage was high. The dye release was initiated slightly after the first peak occurred at Sunnydale. Peak flows for Channel were 520 cfs and 165 cfs. The second peak at Sunnydale was 60 cfs.

CCSF has conducted an analysis to compare the volume of overflows measured this year with anticipated future overflows assuming all Bayside facilities are completed. Under future development, the storms on 22 February, 28 February, and 26 March have a return frequency between one and eight times per year. The storm on 13 February has a return frequency of approximately once in five years.

CONTINUOUS DYE RELEASES

Dye was injected upstream of the overflow points for a period of several hours during storms. The dye concentration was then traced in the channels and Bay with a boat-mounted flourometer. Boat transects were made to determine the spatial and temporal extent and concentration of the dye patch which served as a tracer for the movement of the combined sewer overflow. This procedure was utilized during all continuous dye releases except Sunnydale where 11 shore stations were used since it was impossible to use a boat due to the shallow water depth and high waves. Depth profiles of dye concentration, temperature, and conductivity were measured from which salinity and dilution* profiles were determined. Appendix A contains typical salinity-depth profiles obtained.

In order to maintain a relatively constant dye concentration leaving the overflow structure, the dye was injected in proportion to the sewage discharge. The dye was injected through flexible tubing into sewer manholes for the Islais and Yosemite releases and at the overflow structure for the Channel and Sunnydale releases.

*Dilution, "S", as defined by Dr. N.H. Brooks and others equals the concentration leaving the overflow divided by the concentration at any point beyond the overflow. The State Water Resources Control Board (SWRCB) defines dilution, "D", as "S-1". For example, an initial dilution defined by Dr. Brooks and most models as 20:1 would be considered as 19:1 by the SWRCB. This report utilizes Dr. Brooks' definition.

Islais Creek

Figure III-7 shows a time sequence of four dye dilution contour maps for the Islais Creek continuous dye release. The first set of contours indicates that the dye did not reach a 10:1 dilution inside the channel. The dilution rapidly increased beyond the pierline--achieving 10:1 at about 400 to 700 feet out--and concentrations returned to background within 1/4 to 1/2 mile. The dye also appeared to hug the shoreline, probably because of the current at the pierline. The patch moved farther to the south than the north due to the incoming tide shown on Figure III-9. The second set of contours shows dilution contours for the period of time between 2006 and 2117. There was still a high dye concentration within the channel, downstream of the bridge, even though the dye patch appeared to have receded near the mouth. The isolated patch to the north may have become detached since this was near slack tide. The two breaks in the patch in the channel was due to a tugboat that was turning its prop intermittently at that time and place. The third set of contours shows that the receding tide pulled the dye patch away from the channel mouth, causing an increase in dilution and several isolated patches. There may have been other patches that were not transected by the boat. There was still a dilution of 5:1 existing upstream of the Third Street bridge, even though this was 7-1/2 hours after the dye release. By about 14 hours after the dye release, most of the dye had disappeared from the channel and away from the mouth, as seen on the fourth set of contours. Concentrations were monitored for about 21 hours after the dye release began.

Figure III-8 shows dye dilution profiles along Islais Creek at four different times. The dye concentrates into a layer in the top 3 feet of water. There is also an isolated patch that persisted under the Third Street bridge after the dye release. It is believed that the dye became entrapped in an eddy system at the northwest side of the bridge. Floating materials have also been observed to become temporarily entrapped in this area. The dye is diluted more rapidly at the pierline than at the Third Street Bridge.

Yosemite

Figures III-10, 11 and 12 summarize the results from the continuous dye release at the Yosemite overflow. Figure III-10 shows the temporal variation in the dilution contours. The combined sewer flow was relatively small and diluted quickly as it spread over the large surface area of the Yosemite Inlet. The water at the head end of Yosemite inlet was too shallow to run dye transects with the boat and

1 mile from the Brisbane Lagoon entrance. Figure III-17 shows the patch movement and the tidal chart at Sunnydale.

Channel

The first slug dye release at Channel (10 gallons at 10 percent concentration) was at 12:15 p.m. on 26 February. This was during high slack tide with a 20-knot northwesterly wind. During the slack water the patch drifted east.

The tidal currents on 26 February were exceptionally strong and as the ebb tide began the dye stretched into a long narrow band roughly 1,100 feet long and 400 feet wide. The dye began moving rapidly north despite the strong northwesterly wind. There was strong turbulence as the dye passed under the piers which further aided the dye dilution and dispersion.

The patch followed the pier line and began moving diagonally outward as it neared the Bay Bridge. By 1:00 p.m. the patch was about 2,000 feet long and 200 feet wide. After 1:00 p.m. the patch moved too rapidly for clear readings of the dye concentration. The patch was visible until it passed under the Bay Bridge but then the concentration fell below visible limits. By 2:00 p.m. there was no visible sign of the dye from the air.

The main influence on the patch movement was the strong tidal ebb current. The wind, which was in opposition to the direction of the tide, seemed to have little effect on the dye patch. Figure III-18 indicates the patch movement, tides and wind.

The second slug dye release at Channel (10 gallons at 10 percent concentration) was at 7:00 a.m. on 27 February. The dye was released during a low slack tide with a light northwesterly wind. Initially the dye formed a circular patch 650 feet in diameter and was centered in the mouth of Channel.

As the flood tide began, the patch split into two parts each roughly 650 feet in diameter. Figure III-19 indicates one patch had moved north under Pier 46 while the other patch had moved south under Pier 48 by 8:30 a.m.

The individual patches could not be traced under the piers. By 9:30 a.m. the tidal flood was at its peak and a portion of one or both patches moved up into Channel. The dye extended from the mouth of Channel to the Third Street Bridge. By this time the patches under the piers to the north and south of Channel were below detectable limits, or had been moved into the channel.

Carried by the flood tide, the patch continued moving up Channel. By 11:00 a.m. a patch, diluted roughly 100:1, was detected reaching 2,000 feet west of the Fourth Street Bridge.

The major influence on patch movement was the tide. Although the wind was in opposition to the direction of the patch movement, the flood tide carried the dye within 550 feet of the overflow structure.

Islais Creek

The slug dye release at Islais Creek (20 gallons at 10 percent concentration) was at 9:00 a.m. on 17 March. The release was during slack tide with moderate winds from the northwest. Figure III-20 shows the movement of the dye and the related tides and winds. For 15 minutes the patch drifted slowly south. As the flood tide currents gained momentum, the patch moved south rapidly in a line approximately 25 yards east of the piers. By 9:40 a.m. the patch had formed into a band 400 feet wide and 1,900 feet long.

As the dye patch moved past the small channel on the south side of Pier 96, a portion of the dye was observed moving in towards the shore. A depth profile taken near the mouth of the channel revealed detectable dye concentrations down to 12 feet with high dye concentrations measured at the surface.

Aided by the wind and the incoming tide the main dye patch continued moving south and by 10:00 a.m. was 300 feet wide and 3,500 feet long. At this time the dye was still concentrated and the patch was clearly visible. The patch appeared to move as a unit to this point with little intermixing with the surrounding Bay water.

As the dye moved south past Hunter's Point it was diluted and dispersed to less than detectable limits. At 10:40 a.m. the patch was at Hunter's Point and was 3,000 feet long. By 11:00 a.m. the patch had moved past Hunter's Point and could no longer be detected.

SUMMARY

The continuous dye releases at Islais, Yosemite and Channel each indicated that the dye field--and thus the wastefield--reached a 10:1 dilution prior to or near the mouth of the channels. The dye remained in a layer within the top 3 feet of the water column. Salinity profiles also confirmed this stratification. This stratification decreases the dilution by restricting vertical mixing. The Sunnydale continuous release showed that the dye field disperses fairly rapidly and never approached the Brisbane culverts.

so dilutions within this area could not be determined. It must be noted, however, that the dilution was 25:1 or greater in areas where the boat could be operated. The wind and tides played a major effect on dispersion of this dye field. Figure III-12 indicates that a slack tide existed and a southerly wind pushed the dye patch northward, creating an "island" to the south. Later the wind shifted and blew from the northwest for the remainder of this dye experiment.

The second set of contours shows isolated patches of low concentration. The third set of contours show the patch moving southwesterly with the ebb tide and in the fourth set the dye continued to move bayward.

Figure III-11 shows two depth profiles indicating the vertical extent of the dye patch. The dye field stayed within the top 3 feet of water. The first profile shows the dye patch isolated by the southerly wind and the second profile shows the effect of the ebb tide on the dye field.

Channel

Figures III-13, 14 and 15 summarize the results from the continuous dye release at the Channel overflow. Dye dilution contours in Figure III-13 indicate that a 10:1 dilution was achieved by the time the dye field moved to the Third Street Bridge. Approximately 11 hours after the dye release ended, dilutions within the channel were 100:1. The dye dilution profiles (Figure III-14) indicate that the wastefield stays within the top 3 feet.

Sunnydale

Dye was also continuously released at the Sunnydale overflow during the 26 March storm. Running transects with a boat was impossible so grab samples were periodically taken at 11 stations along the shore (Figure III-16). The dilutions are shown on Table III-4. The dye never touched the shoreline south of the overflow structure. It moved easterly with the ebb tide toward Candlestick point but was diluted considerably.

In conclusion, the continuous dye releases at Islais, Yosemite and Channel each indicated that the dye field--and thus the wastefield--reached a 10:1 dilution prior to or near the mouth of the channels. The dye remained in a layer within the top 3 feet of the water column. Salinity profiles also confirmed this stratification.

The dye field concentrations became insignificant within a half day after the end of the dye release.

The Sunnydale continuous release showed that the dye field disperses fairly rapidly. It appears from the data taken that the dye-waste-field never approached the Brisbane culverts. These results were similar to those obtained from the Sunnydale slug release.

SLUG DYE RELEASES

Slug dye releases were conducted at four times during the study period; once at the Sunnydale Overflow, twice at the mouth of Channel, and once at the mouth of Islais Creek. The dye was released at the end of the pier line from a boat.

The resulting dye patch was traced by boat which ran transects across the moving dye patches to define the dimensions of the dye field. For Sunnydale, aerial photographs of the patch were also taken.

Sunnydale

The dye patch (20 gallons at 5 percent concentration) at the Sunnydale Overflow was released at 10:00 a.m. on 1 February during slack tide and was traced both by boat and aerial photography. The patch initially moved slowly southwest and by 11:30 a.m. the patch dimensions were 400 feet by 800 feet.

By 1:30 p.m. the flood tide current was at its peak and the dye reached its most southern point. The patch was roughly 1,500 feet long and its tip was 2,000 feet south of the overflow structure. The dye extended into shore at a point immediately south of the overflow. At this time the patch was about 1 mile north of the Brisbane Lagoon entrance and it never approached closer.

Aided by the westerly wind the dye began moving rapidly east. At 2:30 p.m. the patch was 600 feet in width and extended 1,800 feet to the east. An hour later the patch was almost 3,000 feet in length.

By 4:30 p.m. the ebb tide began and the wind had risen to 12 knots. Aided by these factors the dye stretched into a thin band reaching to Candlestick Point. As the dye left the protection of the cove it was quickly dispersed to below visible limits. By 6:00 p.m. remnants of the patch could still be seen from the air but visible traces were gone by the next morning.

The main influence on the patch movement at Sunnydale appeared to be the wind and the tides. Although the patch initially moved south after release, it was always at least

The dye field concentrations became insignificant within a half day after the end of the dye release.

The dye patches at Channel during the ebb tide and at Islais were diffused and diluted much faster than the other patches. The velocity of the mid-patch was about 150 feet/minute for the Islais release and roughly 180 feet/minute for the Channel slug released at high slack. The patch velocities for the second Channel release, during flood tide, and for Sunnydale were considerably lower, averaging about 30 feet/minute for both patches.

The movement of the dye at Channel was affected primarily by the tide. At the first Channel release, the dye was carried rapidly north by the strong ebb current. At the second release, the flood tide moved the dye into Channel towards the overflow structure. In both cases the movement of the dye was in opposition to the direction of the prevailing wind. At Sunnydale the wind and tides moved the patch east. At Islais the flood tide and the northerly wind acted in complement to move the dye patch rapidly south.

The dilution rates of the four patches also differed markedly. The first release at Channel was below detectable limits within an hour and a half after release. At Islais, there was little dilution in the patch for the first hour and a half as it moved south. As the patch approached Hunter's Point, it began to disperse and within 2 hours after release, the mid-patch dilution was about 100:1. As the patch passed Hunter's Point it dropped below detectable limits. At the second Channel release, a mid-patch dilution of 100:1 was reached within 4 hours after release. The dilution of the dye which moved up into Channel was also 100:1. At Sunnydale the dilution was fairly low until the dye moved beyond Candlestick Point. Within 6 hours after release the mid-patch dilution was 100:1. All patch releases were subject to more vertical dilution since they were released into Bay water unstratified by low salinity CSO wastefields.

TABLE III-1

DATES OF DYE EXPERIMENTS

Location	Dye Release	Date
Sunnydale	Slug	1 February
Islais	Continuous (aborted)	13 February
Islais	Continuous	20 February
Channel	Slug	26 February
Channel	Slug	27 February
Yosemite	Continuous	28 February
Islais	Slug	17 March
Channel	Continuous	26 March
Sunnydale	Continuous	26 March

TABLE III-2

TIDE CHART
STAGES AND SLACKS AT POTRERO POINT

Date	Time	Stage Height (ft)	Slack	Time	Stage Height (ft)	Slack	Time	Stage Height (ft)	Slack	Time	Stage Height (ft)	Slack
	High Water			Low Water			High Water			Low Water		
FEB												
1	0318	6.4	0353	0907	1.4	1016	1509	5.7	1640	2114	0.5	2231
2	0405	6.5	0442	1017	1.3	1124	1620	5.1	1712	2209	1.2	2327
3	0455	6.5	0534	1130	1.2	1234	1744	4.7	1825	2304	1.8	0028
4	0550	6.5	0628	1245	0.9	1341	1919	4.6	1938	——	——	——
	Low Water			High Water			Low Water			High Water		
5	0014	2.3	0132	0644	6.5	0723	1351	0.6	1443	2040	4.7	2046
6	0113	2.5	0233	0741	6.5	0816	1447	0.4	1538	2142	5.0	2145
7	0225	2.6	0329	0830	6.5	0907	1536	0.1	1626	2233	5.2	2235
8	0319	2.6	0418	0918	6.5	0955	1617	-0.1	1710	2314	5.3	2319
9	0405	2.5	0501	1000	6.5	1138	1652	-0.2	1749	2350	5.4	2358
10	0447	2.4	0541	1039	6.5	1119	1724	-0.2	1826	——	——	——
	High Water			Low Water			High Water			Low Water		
11	0022	5.4	0034	0522	2.3	0618	1115	6.4	1158	1755	-0.2	1900
12	0049	5.4	0108	0558	2.2	0654	1150	6.2	1236	1826	-0.1	1932
13	0116	5.5	0141	0636	2.0	0730	1225	6.0	1314	1855	0.1	2003
14	0142	5.5	0213	0708	1.9	0808	1302	5.7	1353	1924	0.4	2033
15	0211	5.6	0245	0745	1.8	0849	1342	5.4	1436	1956	0.7	2104
16	0242	5.7	0318	0829	1.7	0936	1428	5.0	1526	2031	1.2	2138
17	0315	5.8	0355	0921	1.6	1032	1523	4.7	1625	2109	1.6	2219
18	0354	5.9	0438	1020	1.4	1135	1637	4.4	1736	2148	2.1	2312
19	0444	6.0	0527	1129	1.1	1243	1811	4.3	1852	2304	2.5	0018
20	0539	6.2	0624	1238	0.7	1349	1944	4.5	2004	——	——	——
	Low Water			High Water			Low Water			High Water		
21	0016	2.7	0131	0641	6.4	0725	1341	0.2	1449	2053	4.8	2107
22	0132	2.7	0238	0740	6.6	0825	1440	-0.3	1543	2148	5.1	2202
23	0236	2.5	0337	0839	6.9	0922	1532	-0.7	1734	2235	5.5	2251
24	0331	2.1	0430	0938	7.1	1018	1621	-1.0	1721	2316	5.8	2337
25	0422	1.7	0521	1030	7.2	1112	1705	-1.1	1807	2358	6.0	0019
26	0512	1.2	0611	1123	7.1	1205	1749	-1.0	1852	——	——	——
	High Water			Low Water			High Water			Low Water		
27	0033	6.2	0101	0602	0.9	0701	1215	6.8	1258	1832	-0.7	1937
28	0112	6.3	0142	0654	0.6	0754	1310	6.4	1352	1915	-0.2	2022

TABLE III-2
(Continued)

Date	Time	Stage Height (ft)	Slack	Time	Stage Height (ft)	Slack	Time	Stage Height (ft)	Slack	Time	Stage Height (ft)	Slack
	High Water			Low Water			High Water			Low Water		
MAR												
1	0153	6.4	0224	0747	0.5	0848	1406	5.9	1449	2001	0.4	2108
2	0235	6.4	0308	0842	0.5	0947	1506	5.4	1550	2048	1.1	2158
3	0317	6.3	0356	0941	0.6	1051	1613	4.9	1655	2140	1.7	2256
4	0416	6.2	0448	1047	0.7	1159	1735	4.7	1806	2242	2.3	0002
5	0500	6.1	0546	1200	0.7	1308	1902	4.6	1957	2358	2.6	0112
6	0600	5.9	0647	1309	0.7	1412	2021	4.8	2023	—	—	—
	Low Water			High Water			Low Water			High Water		
7	0110	2.7	0218	0702	5.9	0748	1410	0.5	1509	2117	5.0	2119
8	0213	2.6	0314	0802	5.9	0844	1501	0.4	1559	2202	5.2	2206
9	0304	2.4	0402	0853	5.9	0935	1543	0.2	1642	2240	5.3	2246
10	0349	2.1	0444	0938	6.0	1021	1619	0.1	1720	2309	5.3	2322
11	0427	1.8	0522	1020	5.9	1104	1651	0.1	1755	2337	5.4	2346
12	0503	1.6	0558	1102	5.9	1144	1723	0.1	1828	—	—	—
	High Water			Low Water			High Water			Low Water		
13	0002	5.5	0027	0535	1.3	0633	1141	5.8	1223	1752	0.3	1858
14	0028	5.5	0057	0610	1.1	0707	1217	5.6	1302	1822	0.5	1927
15	0053	5.6	0126	0643	0.9	0743	1258	5.4	1342	1851	0.8	1956
16	0121	5.7	0155	0721	0.8	0821	1340	5.2	1426	1923	1.2	2026
17	0153	5.8	0226	0803	0.7	0904	1430	4.9	1515	1948	1.6	2101
18	0227	5.9	0301	0849	0.6	0955	1527	4.7	1614	2041	2.1	2144
19	0309	5.9	0344	0947	0.5	1057	1640	4.5	1823	2136	2.5	2243
20	0359	5.9	0439	1050	0.4	1207	1806	4.5	1836	1052	2.7	0001
21	0500	5.9	0546	1201	0.2	1317	1925	4.7	1945	—	—	—
	Low Water			High Water			Low Water			High Water		
22	0012	2.7	0123	0612	6.0	0659	1308	0.0	1421	2028	5.0	2045
23	0125	2.5	0232	0721	6.1	0808	1410	-0.3	1518	2116	5.3	2137
24	0229	2.0	0331	0827	6.3	0912	1504	-0.5	1610	2201	5.7	2223
25	0324	1.4	0423	0929	6.4	1011	1554	-0.6	1658	2204	5.9	2305
26	0415	0.8	0513	1026	6.4	1106	1638	-0.6	1743	2319	6.2	2345
27	0502	0.3	0601	1121	6.4	1200	1722	-0.3	1827	2356	6.3	0025
28	0550	-0.1	0648	1216	6.2	1252	1806	0.1	1909	—	—	—
	High Water			Low Water			High Water			Low Water		
29	0035	6.4	0104	0639	-0.3	0736	1308	6.2	1344	1848	0.6	1932
30	0113	6.4	0143	0725	-0.3	0826	1403	5.5	1438	1933	1.2	2037
31	0153	6.3	0224	0816	-0.2	0919	1502	5.2	1535	2022	1.8	2126

TABLE III-3

WIND DATA
SAN FRANCISCO INTERNATIONAL AIRPORT

Hour	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)
01	FEB	230	4		330	9		180	4		320	4		310	5
04		300	3		360	9		200	4		190	2		350	3
07		100	4		40	12		300	3		250	4		290	3
10	1	100	5	2	40	15	3	140	6	4	30	4	5	90	5
13		230	11		30	7		310	3		30	6		290	12
16		280	12		50	6		300	9		280	7		310	9
19		290	12		260	8		300	9		310	6		270	10
22		300	13		190	4		180	4		350	3		290	11
01		290	12		290	9		30	3		00	0		120	6
04		280	8		350	6		250	3		270	3		350	3
07		00	0		300	3		310	5		230	3		150	5
10	6	90	6	7	50	6	8	150	4	9	50	4	10	60	4
13		290	13		20	5		300	10		40	5		70	6
16		280	15		20	4		290	10		30	6		310	9
19		280	11		290	8		200	6		300	12		290	8
22		290	9		80	3		200	5		300	12		330	5
01		360	4		40	4		150	9		290	20		190	4
04		330	4		130	6		00	0		260	17		170	7
07		220	4		100	6		190	4		310	10		130	8
10	11	50	4	12	130	12	13	140	13	14	290	14	15	100	10
13		20	6		200	17		150	15		300	12		210	12
16		30	5		200	8		170	20		300	10		200	12
19		150	3		200	7		180	6		220	8		190	14
22		210	3		170	14		290	13		230	4		170	13
01		170	7		180	4		120	7		00	0		190	4
04		200	5		290	2		130	6		300	4		180	6
07		280	8		230	3		240	5		00	0		120	10
10	16	260	14	17	70	4	18	120	5	19	60	5	20	160	10
13		290	12		40	7		170	9		60	6		170	18
16		290	11		90	7		260	8		300	10		20	7
19		230	6		180	6		260	7		300	8		240	10
22		190	6		140	3		230	5		290	6		210	8
01		250	18		270	8		270	8		210	4		140	6
04		220	17		200	5		290	6		310	3		00	0
07		240	15		190	9		180	6		190	4		90	5
10	21	280	18	22	220	19	23	250	6	24	120	6	25	60	5
13		280	16		260	9		250	10		20	6		180	6
16		300	19		240	16		280	8		300	8		160	7
19		290	17		240	6		240	8		260	6		250	9
22		280	12		200	6		210	4		60	4		250	6

TABLE III-3
(Continued)

Hour	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)
01	FEB	300	11		280	4		290	8						
04		280	9		300	11		160	6						
07		300	16		290	7		170	7						
10	26	290	17	27	300	10	28	220	13						
13		310	20		300	20		190	8						
16		290	18		290	17		200	12						
19		300	16		280	15		180	12						
22		270	8		290	13		300	14						
01	MAR	300	19		310	8		10	5		360	4		270	6
04		300	15		290	10		120	4		50	5		300	6
07		300	11		140	3		100	5		90	5		230	4
10	1	310	19	2	120	5	3	100	6	4	120	9	5	10	8
13		300	21		100	8		80	6		50	6		40	3
16		300	20		160	7		30	8		310	11		300	10
19		300	19		70	6		330	6		290	11		310	11
22		300	12		120	3		300	8		300	10		300	9
01		300	4		310	12		300	12		300	4		230	10
04		300	4		300	8		300	12		360	4		220	6
07		190	4		140	4		170	4		00	0		200	8
10	6	30	6	7	60	6	8	100	5	9	50	5	10	190	6
13		10	6		50	5		60	5		50	6		60	5
16		300	16		280	14		30	6		150	6		230	12
19		300	11		300	18		300	16		290	5		290	8
22		290	29		300	12		330	12		190	4		300	7
01		350	5		00	0		310	11		200	8		180	6
04		270	3		240	5		300	11		170	6		190	9
07		300	6		220	4		00	0		180	5		60	4
10	11	50	5	12	70	4	13	210	8	14	180	8	15	190	3
13		300	9		50	3		230	9		200	14		300	17
16		290	12		80	3		240	12		200	12		290	19
19		280	11		300	12		190	6		190	8		290	18
22		250	5		300	10		240	10		180	10		290	14
01		220	8		340	5		280	6		300	5		320	6
03		250	6		280	6		290	7		320	6		250	7
07		120	9		340	6		170	3		10	7		210	4
10	16	130	8	17	30	7	18	30	6	19	330	5	20	60	6
13		100	8		300	11		360	5		60	6		310	10
16		90	4		280	14		290	16		290	13		280	13
19		210	7		290	13		280	15		280	11		280	6
22		170	3		240	7		290	15		290	4		270	10

TABLE III-3
(Continued)

Hour	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)	Day	Dir	Speed (Kn)
01	MAR	280	8		290	5		190	5		170	4		280	10
04		220	5		180	5		230	5		220	4		230	5
07		220	7		70	5		220	3		220	3		260	4
10	21	200	9	22	100	7	23	80	6	24	90	5	25	320	10
13		230	10		90	7		50	7		40	7		310	14
16		210	10		20	3		270	9		290	14		270	17
19		230	6		210	12		300	9		280	11		260	10
22		250	8		190	5		280	9		290	4		270	8
01		240	8		150	20		150	8		280	9		310	12
04		160	2		170	19		180	4		290	9		300	13
07		170	6		170	25		170	9		310	6		300	14
10	26	160	6	27	210	21	28	130	13	29	290	15	30	310	9
13		150	15		220	21		120	14		290	13		290	11
16		150	13		210	14		120	10		290	14		300	14
19		150	12		200	7		300	7		300	13		280	17
22		130	15		220	4		290	6		290	13		280	7
01		00	0												
04		00	0												
07		00	0												
10	31	110	4												
13		330	5												
16		300	14												
19		280	16												
22		280	10												

TABLE III-4

SPATIAL AND TEMPORAL EXTENT OF DILUTION
FOR THE SUNNYDALE DYE RELEASE

Shore Station	Dilution at Time					
	22:00	24:00	02:00	04:00	07:30	09:45
D1	*	*	*	*	*	*
D2	*	*	*	*	*	*
D3	*	*	*	*	*	*
D4	*	*	*	*	*	*
D5	*	*	*	*	*	*
D6	*	*	*	*	*	*
D7	14:1	116:1	10:1	23:1	85:1	*
D8	*	*	6:1	23:1	66:1	*
D9	*	*	*	*	110:1	*
D10	*	*	*	*	135:1	*
D11	*	*	*	*	247:1	*

*Indicates no dye, or a dilution greater than 300:1.

Notes: Dye experiment was conducted on 26-27 March 1979.

The location of the stations is shown on Figure III-16.

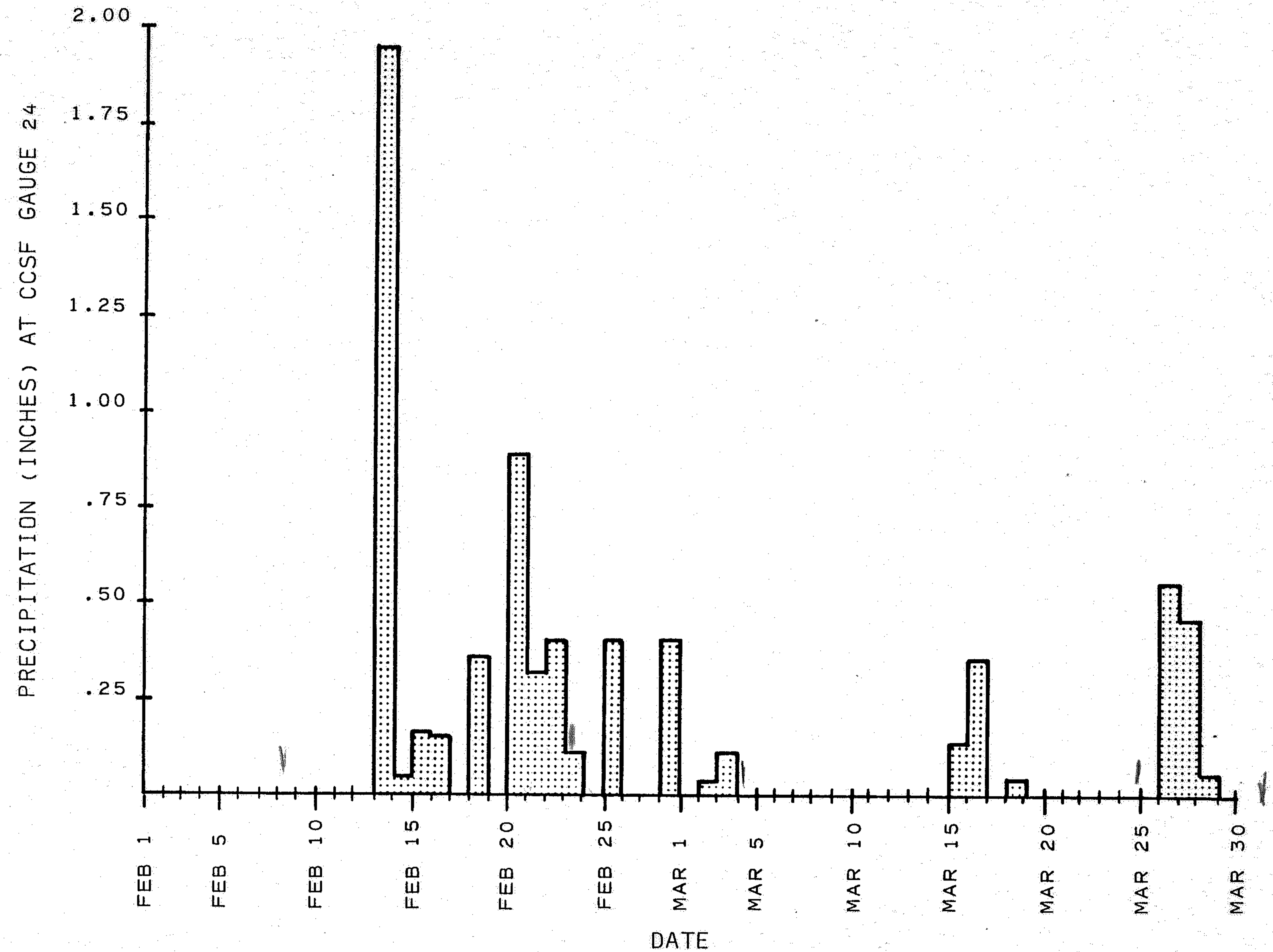
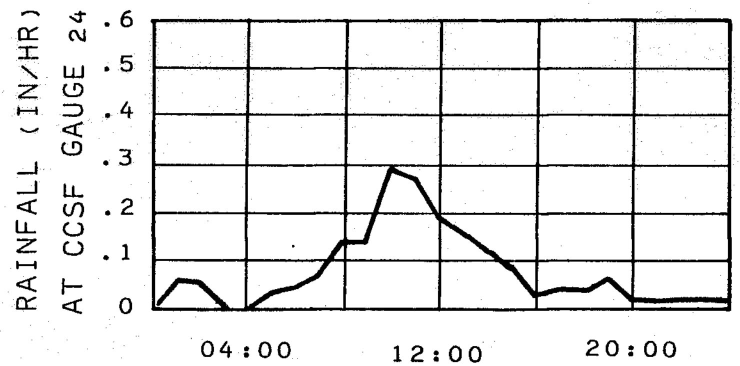


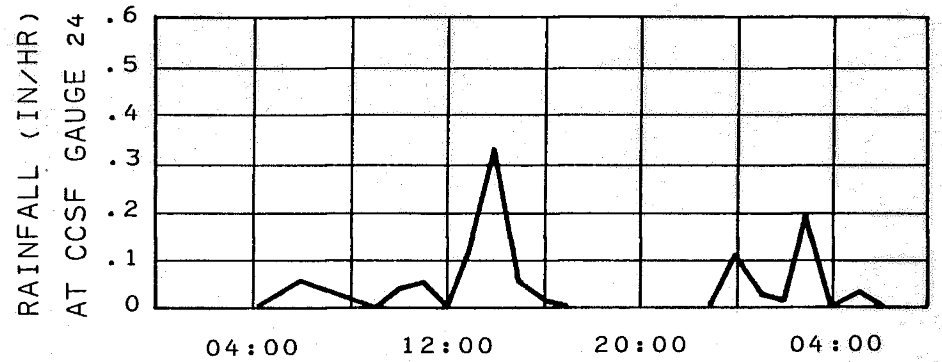
FIGURE III-1

DAILY RAINFALL RECORDS



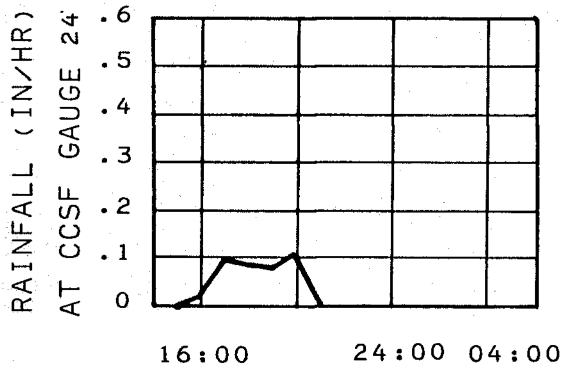
FEBRUARY 13

WATER QUALITY AT ISLAIS



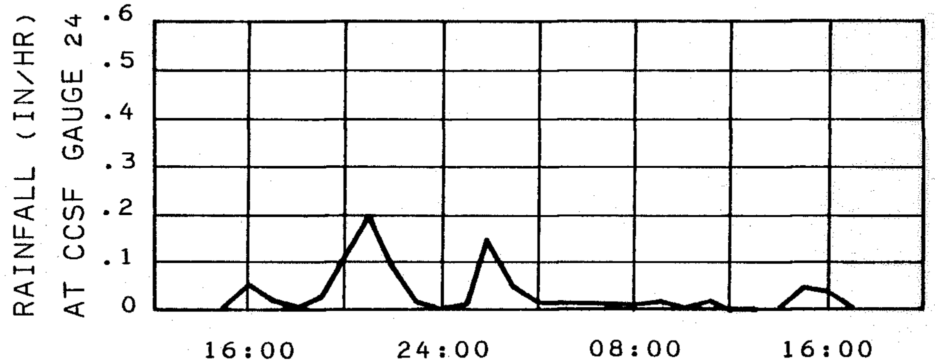
FEBRUARY 20

DYE RELEASE AT ISLAIS



FEBRUARY 28

DYE RELEASE AND WATER QUALITY AT YOSEMITE



MARCH 26-27

DYE RELEASE AND WATER QUALITY AT SUNNYDALE AND CHANNEL

FIGURE III-2

RAINFALL RECORDS DURING WATER QUALITY AND DYE ACTIVITIES

CH2M HILL

FEBRUARY 20, 1979

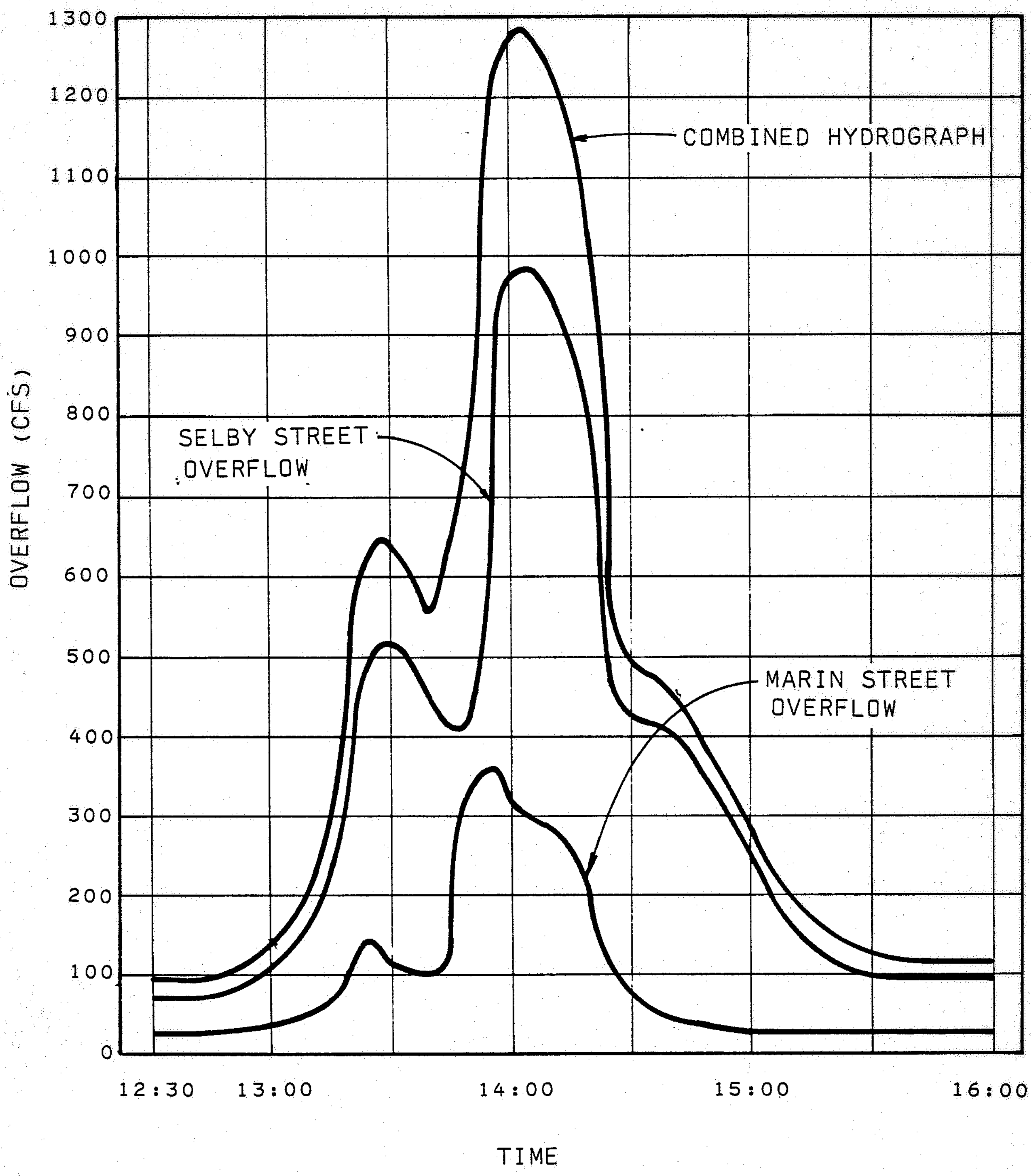


FIGURE III-3

OVERFLOWS INTO ISLAIS CREEK

CH2M HILL

FEBRUARY 28, 1979

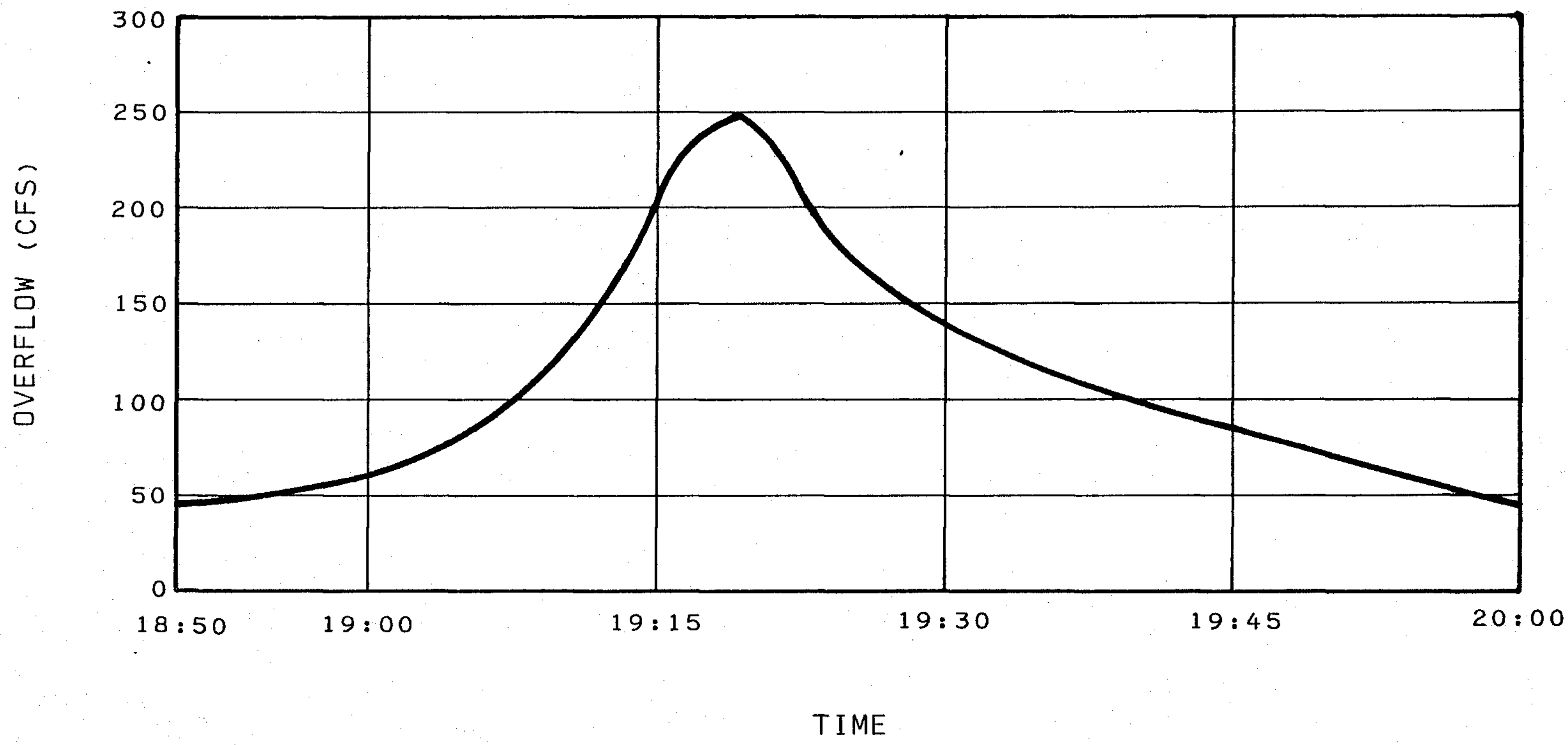


FIGURE III-4

OVERFLOW FROM YOSEMITE AND INGALLS SEWERS

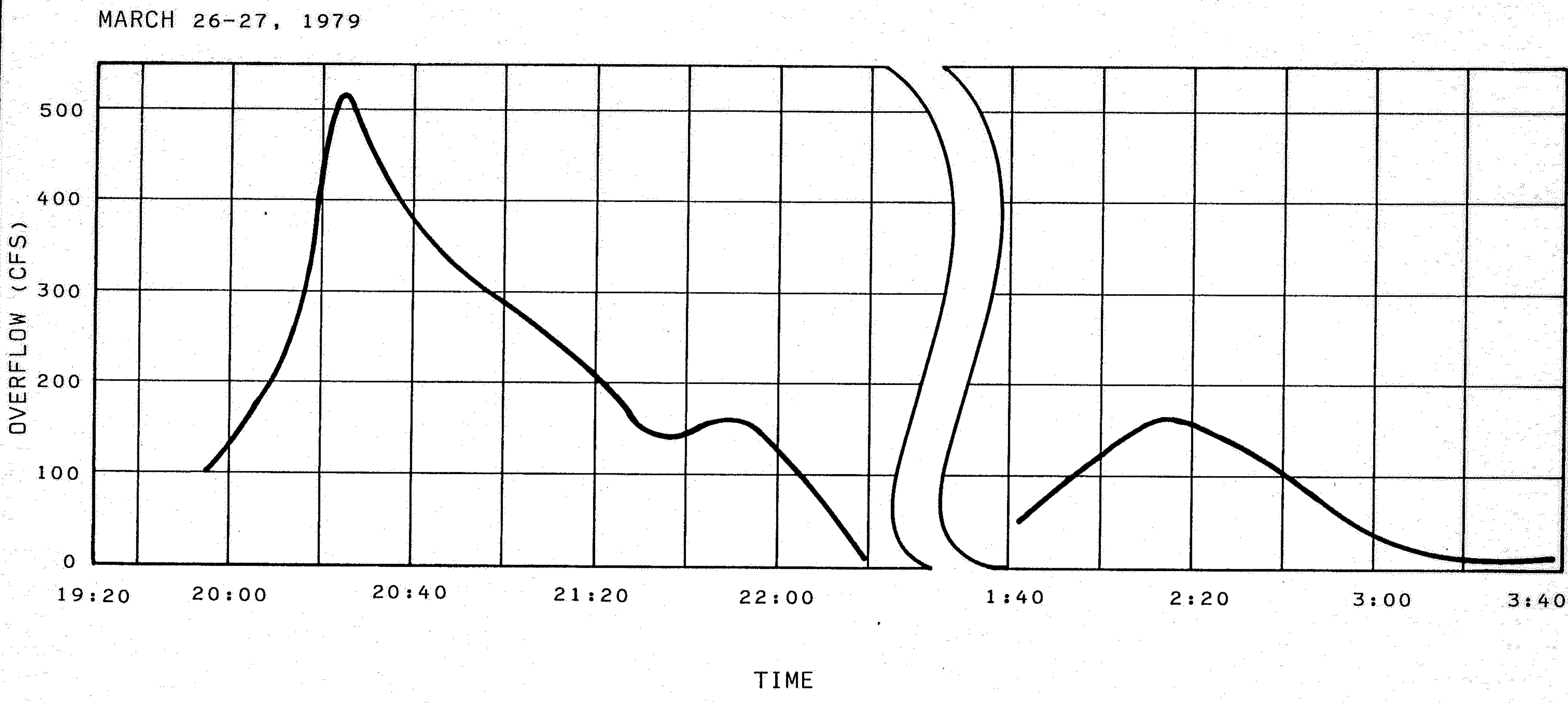


FIGURE III-5

OVERFLOW FROM THE DIVISION SEWER (CHANNEL)

MARCH 26-27, 1979

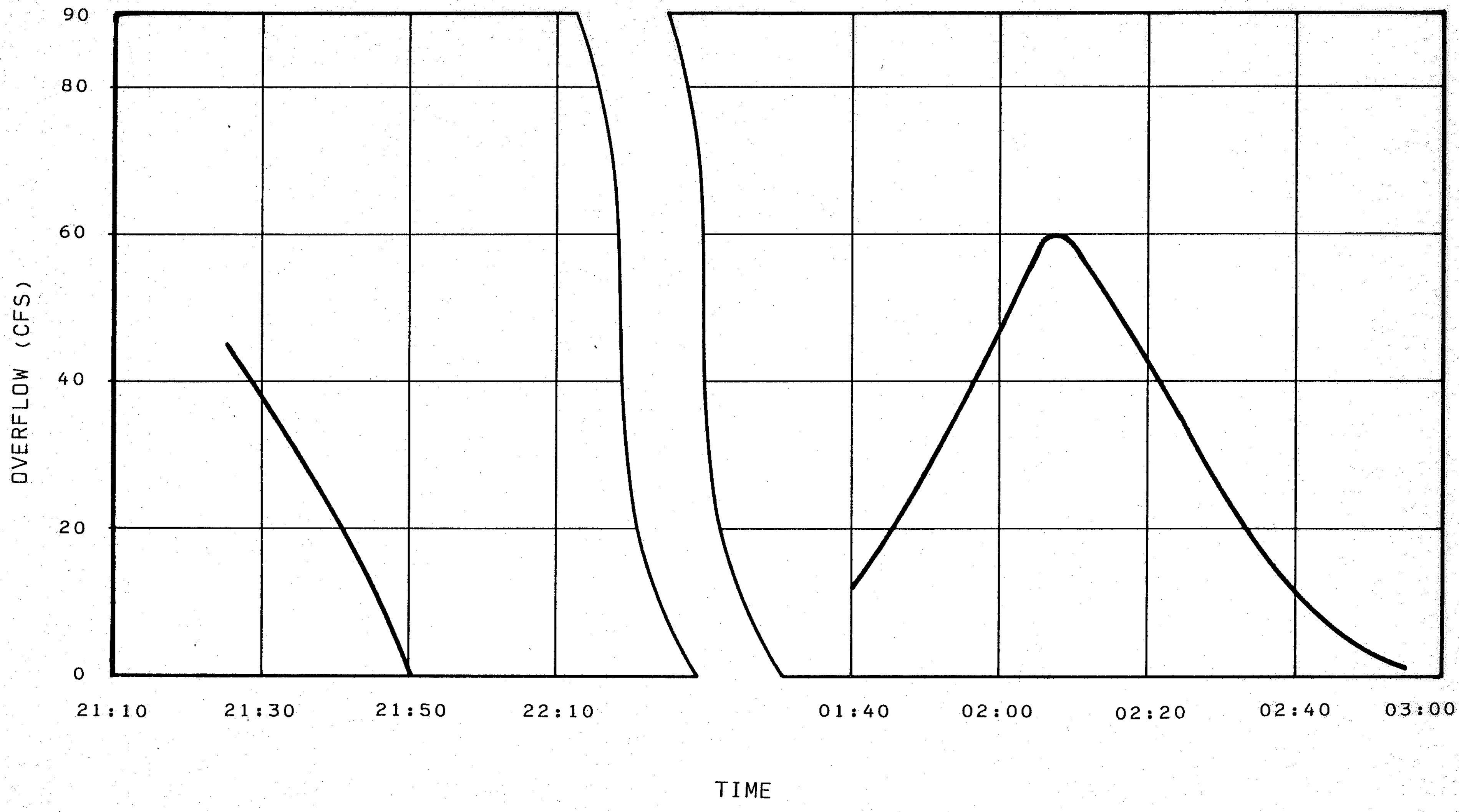


FIGURE III-6

OVERFLOW FROM THE SUNNYDALE SEWER

CH2M HILL

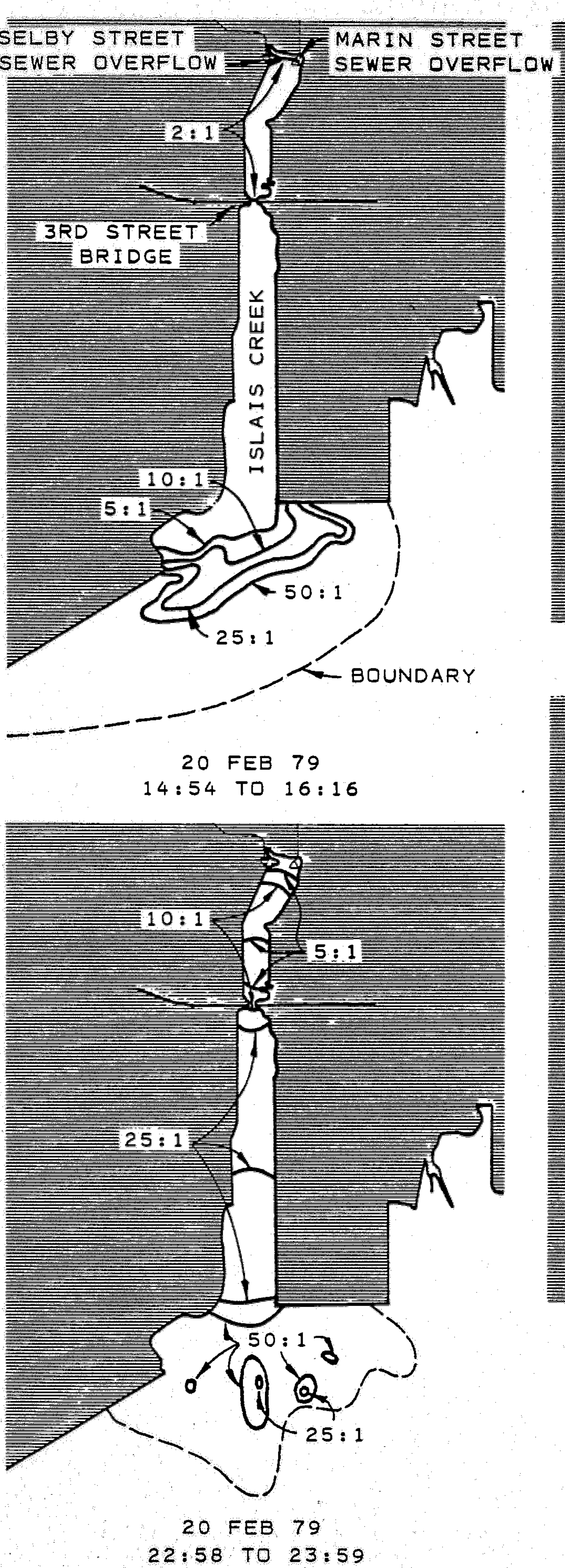


FIGURE III-7
ISLAIS CREEK -
DYE DILUTION CONTOURS

CH2M HILL

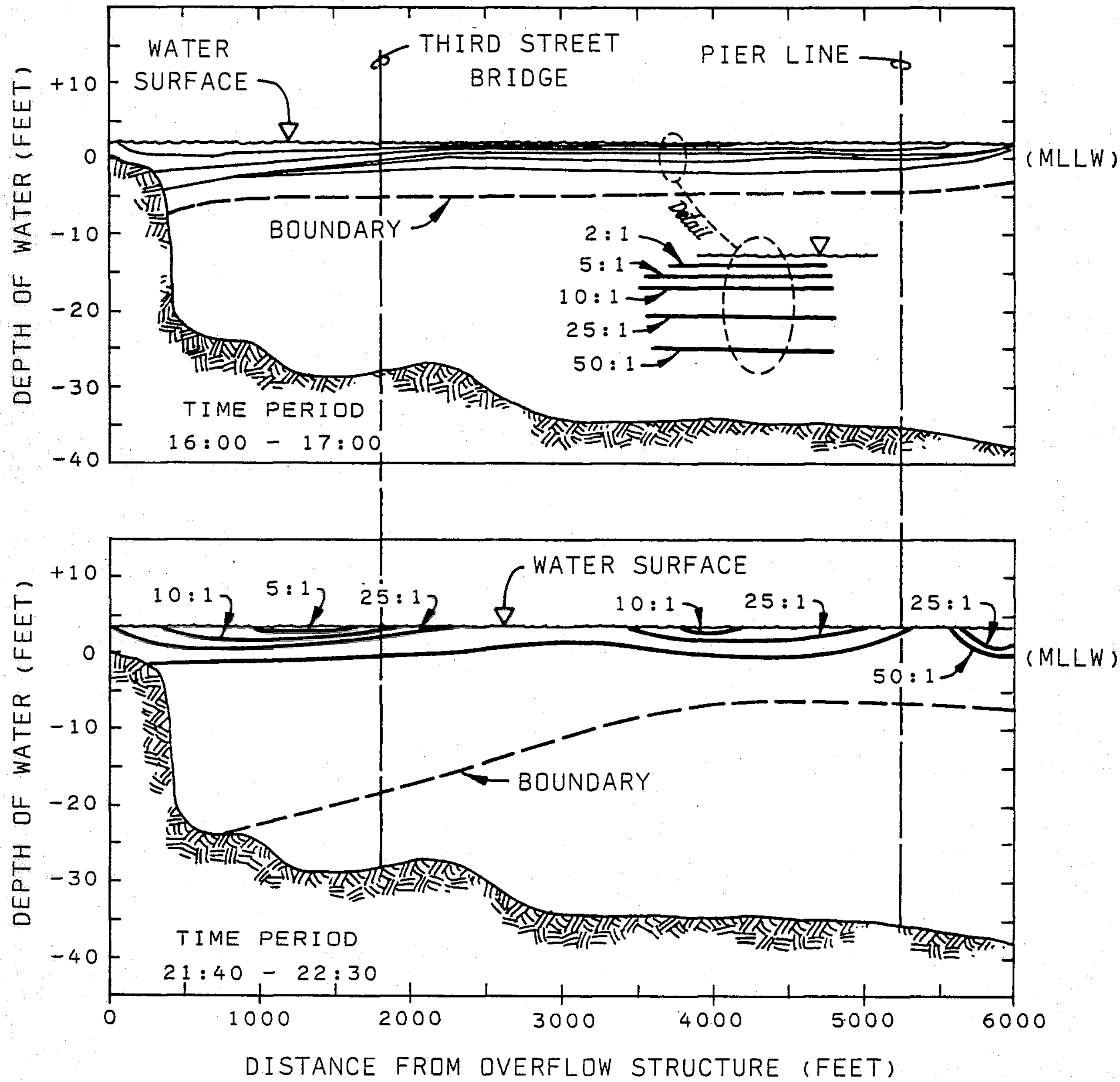


FIGURE III-8
ISLAIS CREEK - DILUTION PROFILES
20 FEBRUARY 1979

CH2M HILL

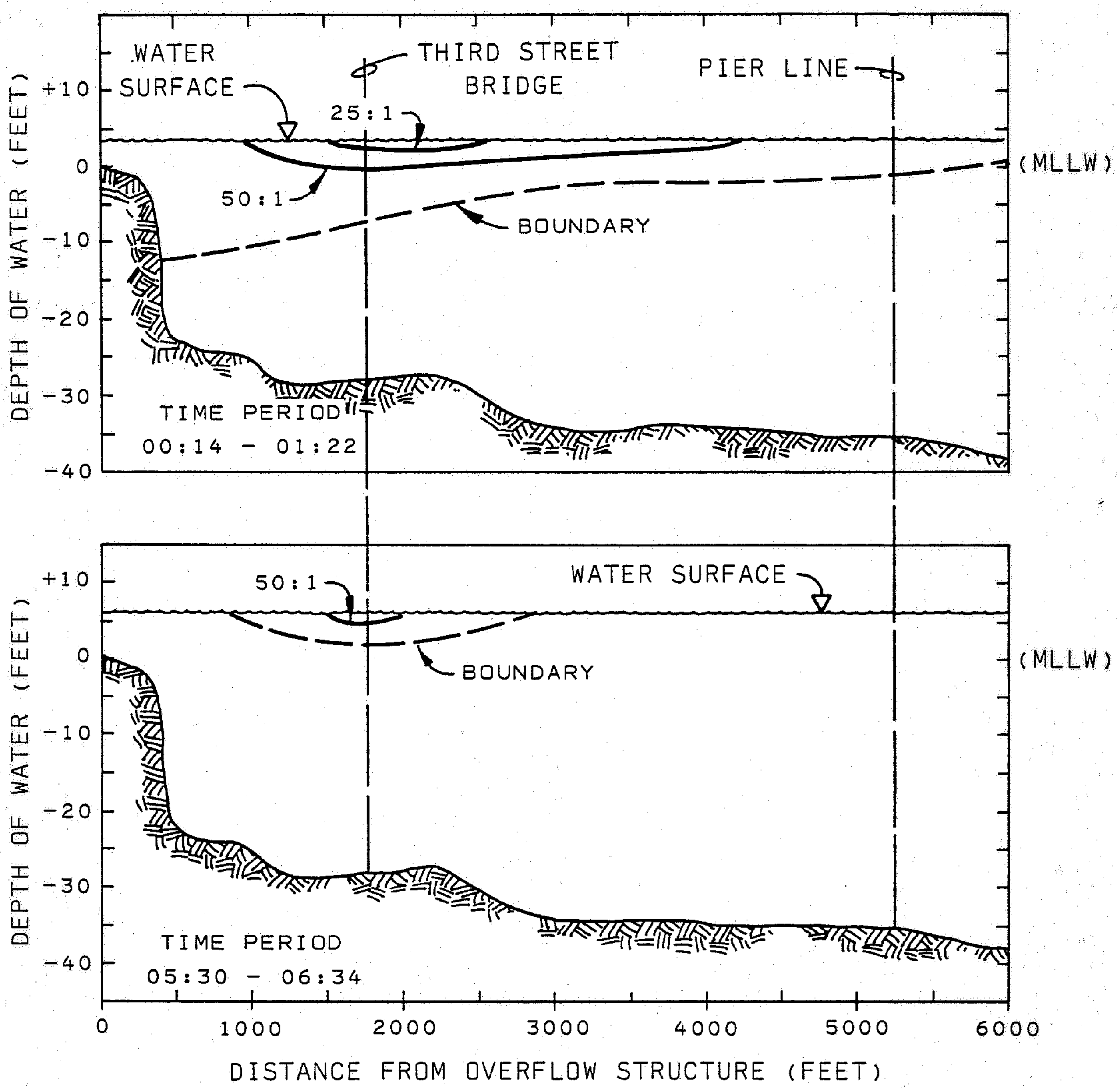
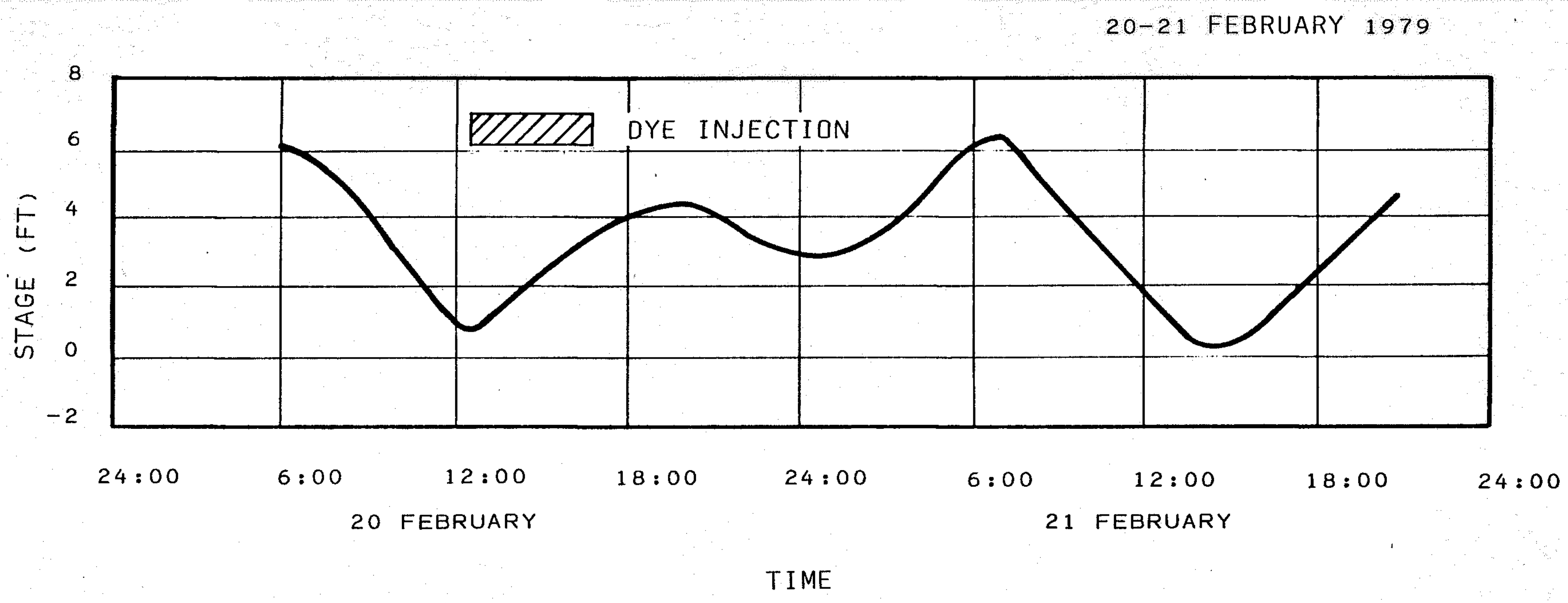


FIGURE III-8(CONTINUED)
ISLAIS CREEK - DILUTION PROFILES
21 FEBRUARY 1979

CH2M HILL



20 FEBRUARY 1979

TIME	WIND DIRECTION	WIND SPEED (KNOTS)
1:00	SSW	4
4:00	S	6
7:00	ESE	10
10:00	SSE	10
13:00	SSE	18
16:00	NNE	7
19:00	WSW	10
22:00	SSW	8

21 FEBRUARY 1979

TIME	WIND DIRECTION	WIND SPEED (KNOTS)
1:00	WSW	18
4:00	SSW	17
7:00	WSW	15
10:00	WNW	18
13:00	WNW	16
16:00	WNW	19
19:00	WNW	17
22:00	WNW	12

FIGURE III - 9

TIDAL STAGE AND WINDS-
ISLAIS CREEK DYE RELEASE

CH2M HILL

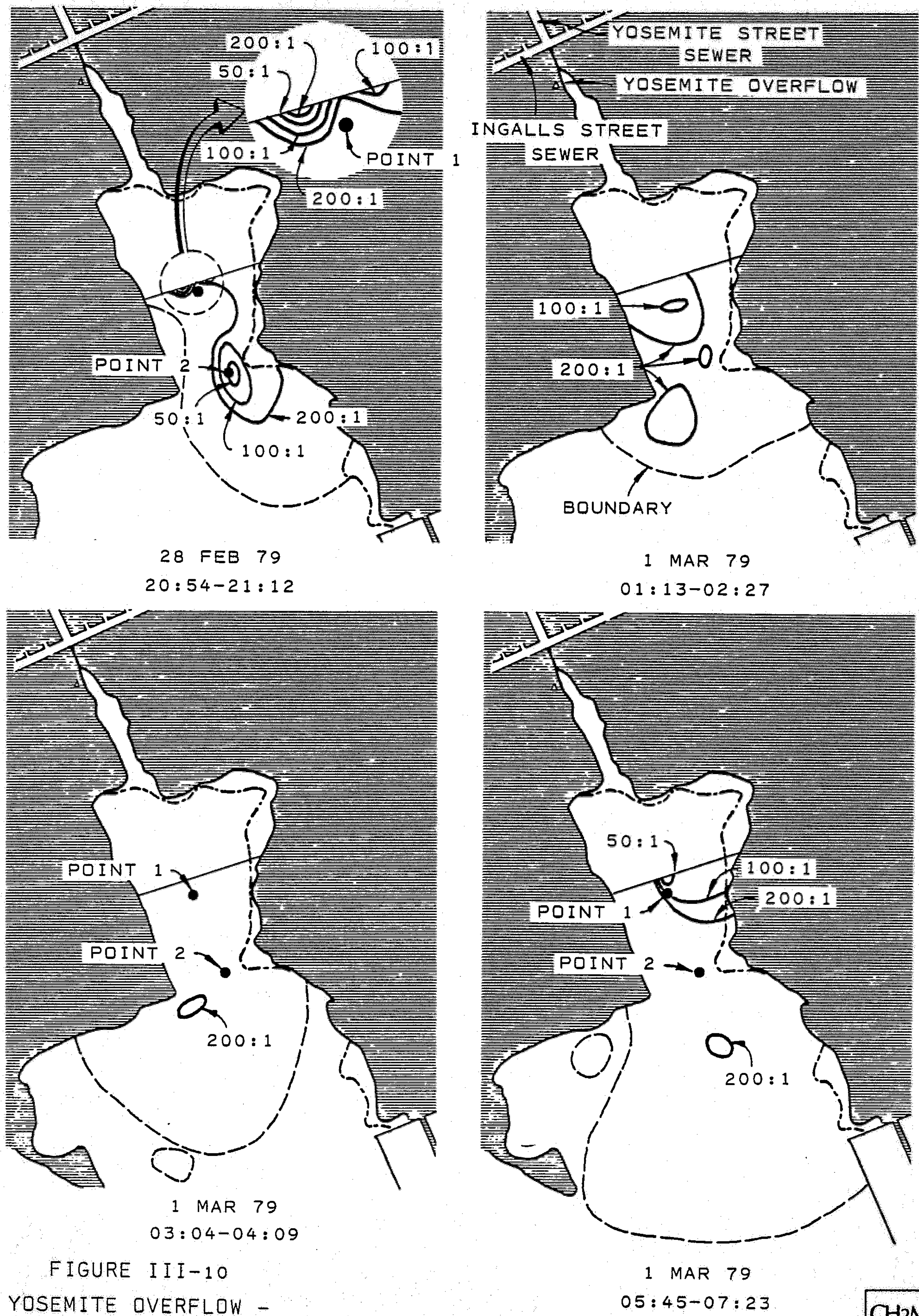


FIGURE III-10
YOSEMITE OVERFLOW -
DYE DILUTION CONTOURS

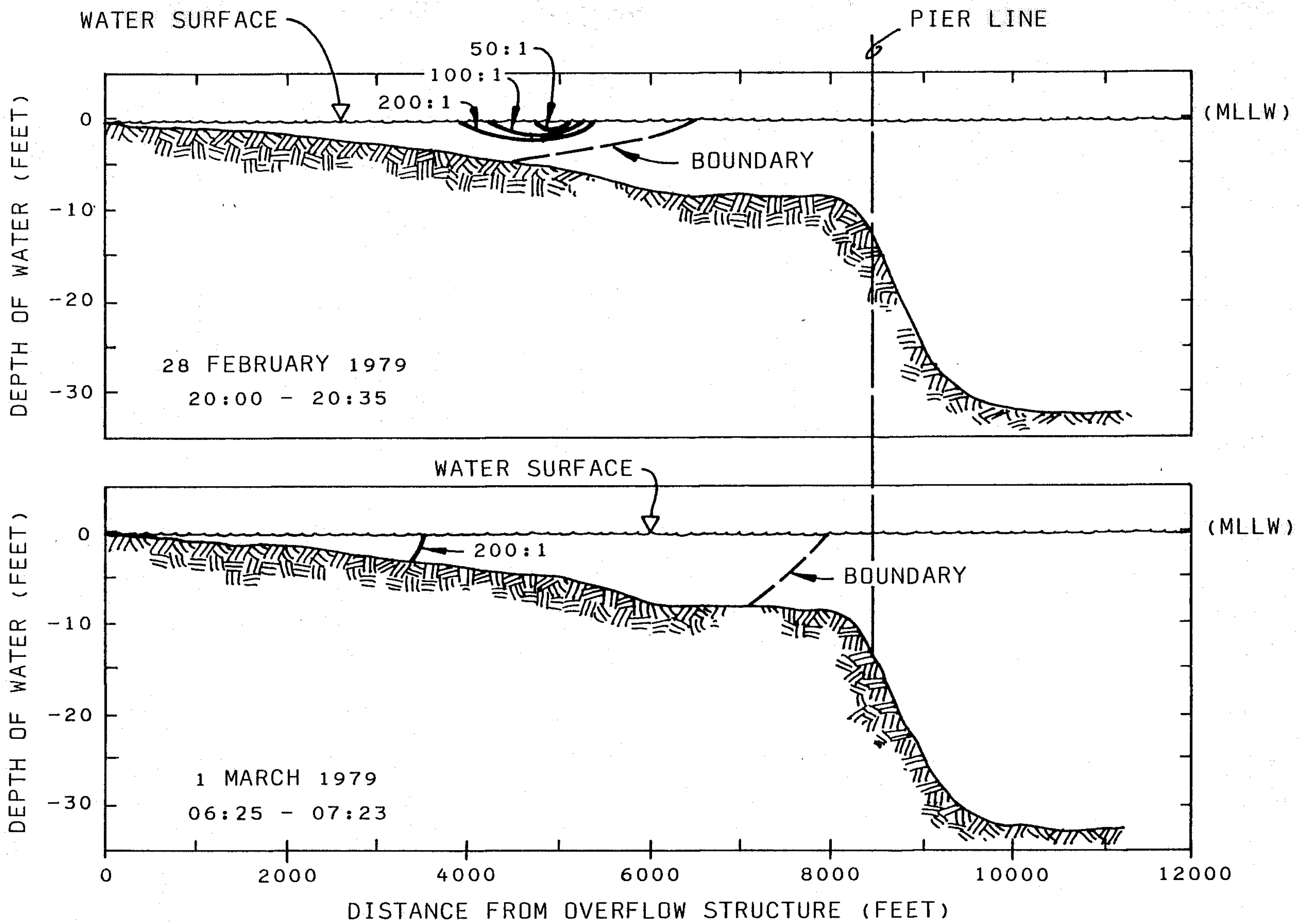
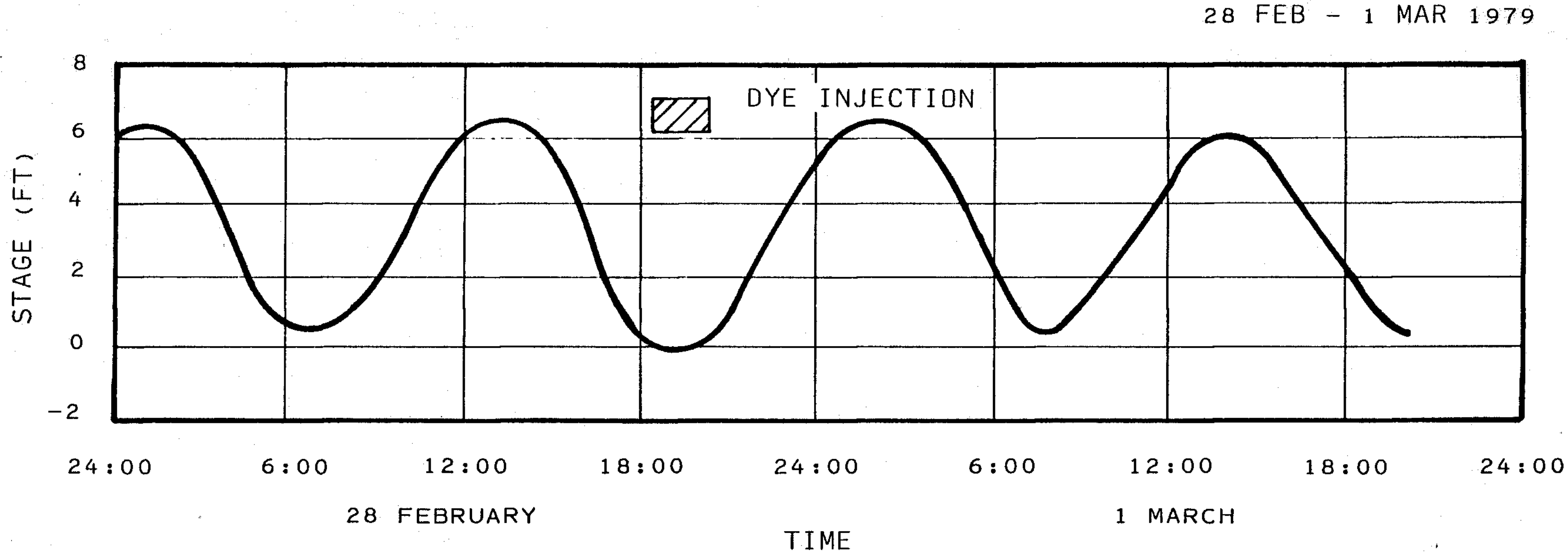


FIGURE III-11
YOSEMITE OVERFLOW - DILUTION PROFILES

CH2M HILL



28 FEBRUARY 1979

TIME	WIND DIRECTION	WIND SPEED (KNOTS)
1:00	WNW	8
4:00	SSE	6
7:00	SSE	7
10:00	SSW	13
13:00	SSW	8
16:00	SSW	12
19:00	S	12
22:00	WNW	14

1 MARCH 1979

TIME	WIND DIRECTION	WIND SPEED (KNOTS)
1:00	WNW	19
4:00	WNW	15
7:00	WNW	11
10:00	WNW	19
13:00	WNW	21
16:00	WNW	20
19:00	WNW	19
22:00	WNW	12

FIGURE III-12
TIDAL STAGE AND WINDS -
YOSEMITE OVERFLOW DYE RELEASE

CH2M HILL

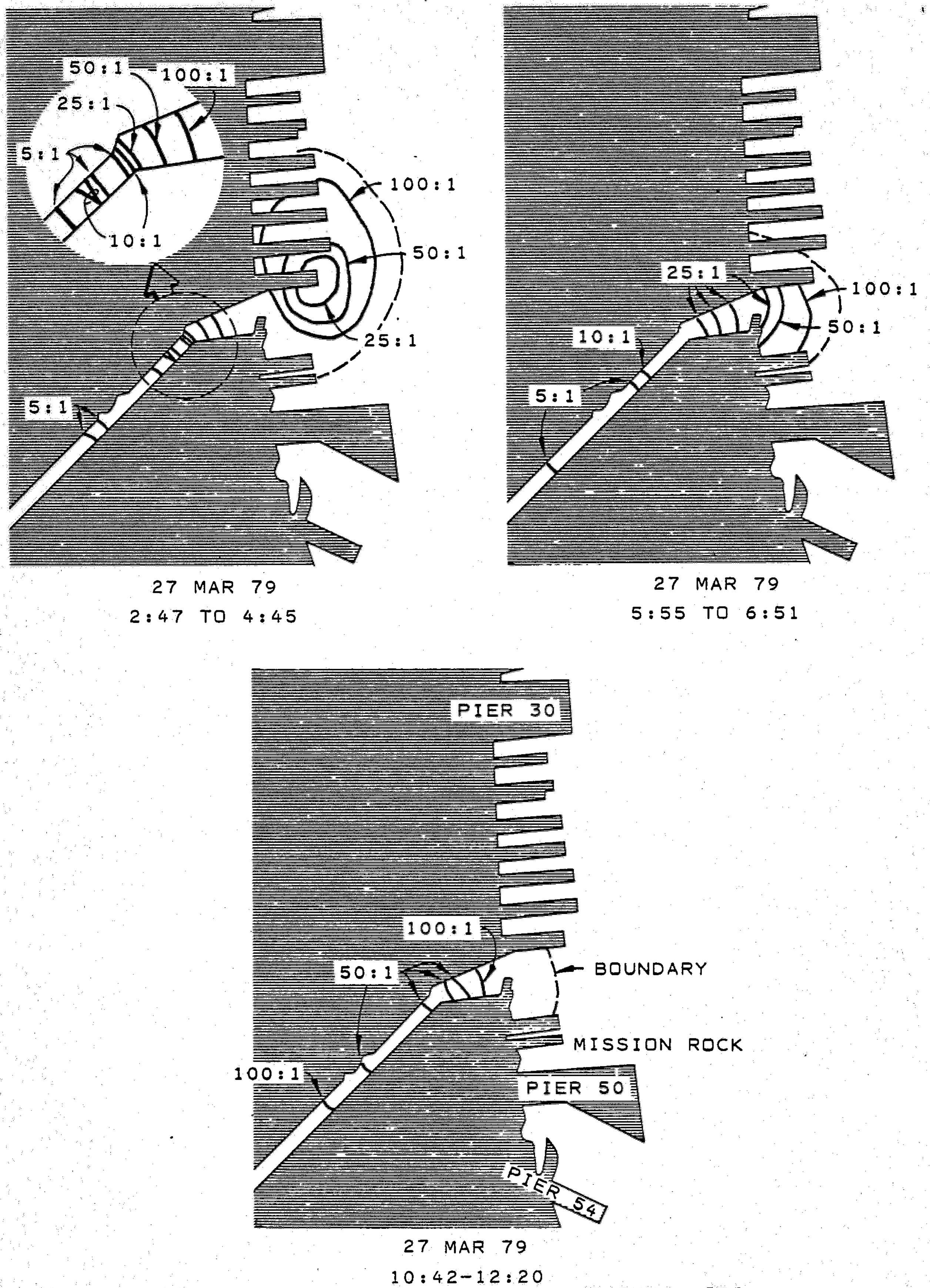


FIGURE III-13
CHANNEL OVERFLOW -
DYE DILUTION CONTOURS

CH2M HILL

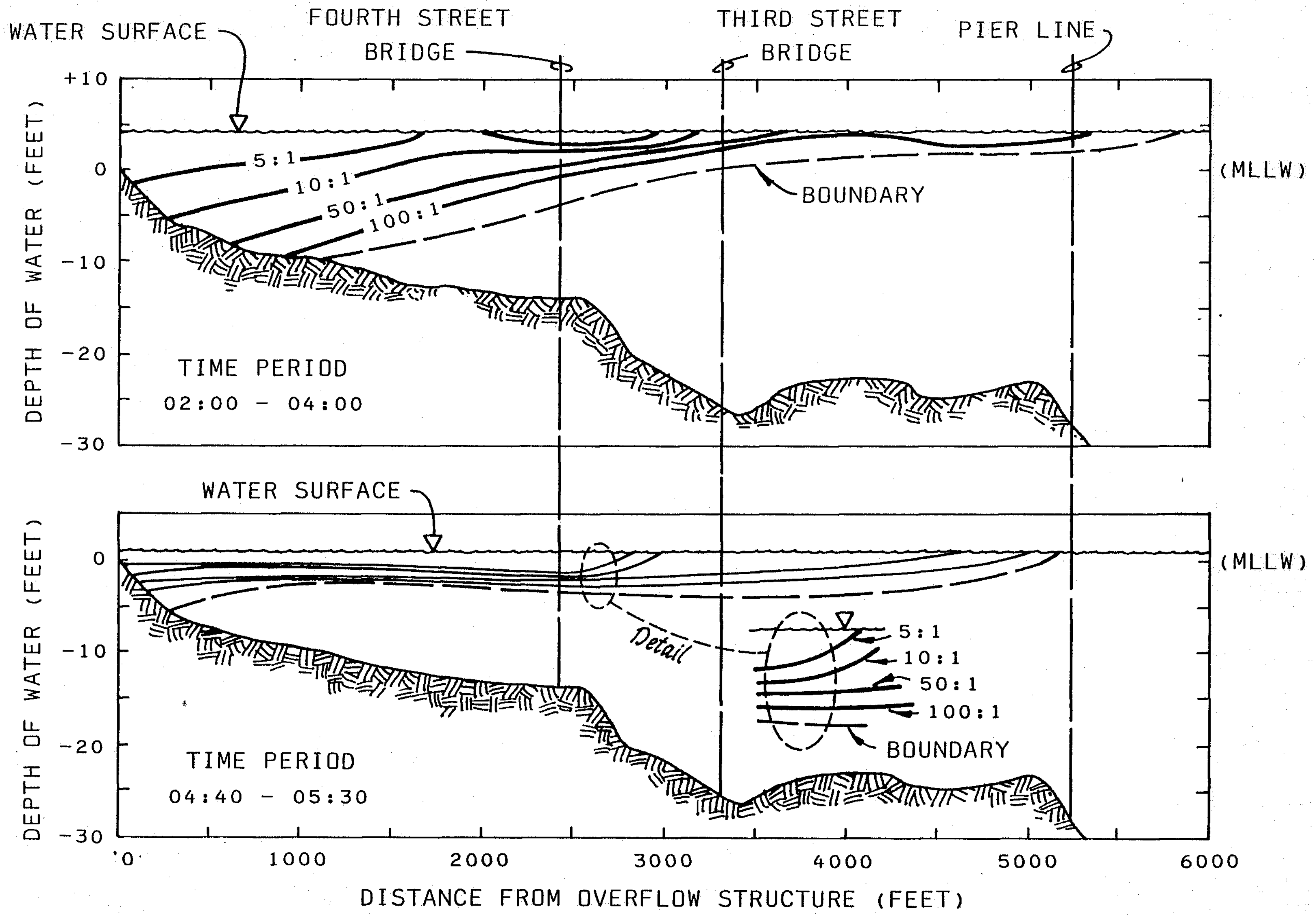


FIGURE III-14
CHANNEL OVERFLOW - DILUTION PROFILES
27 MARCH 1979

CH2M HILL

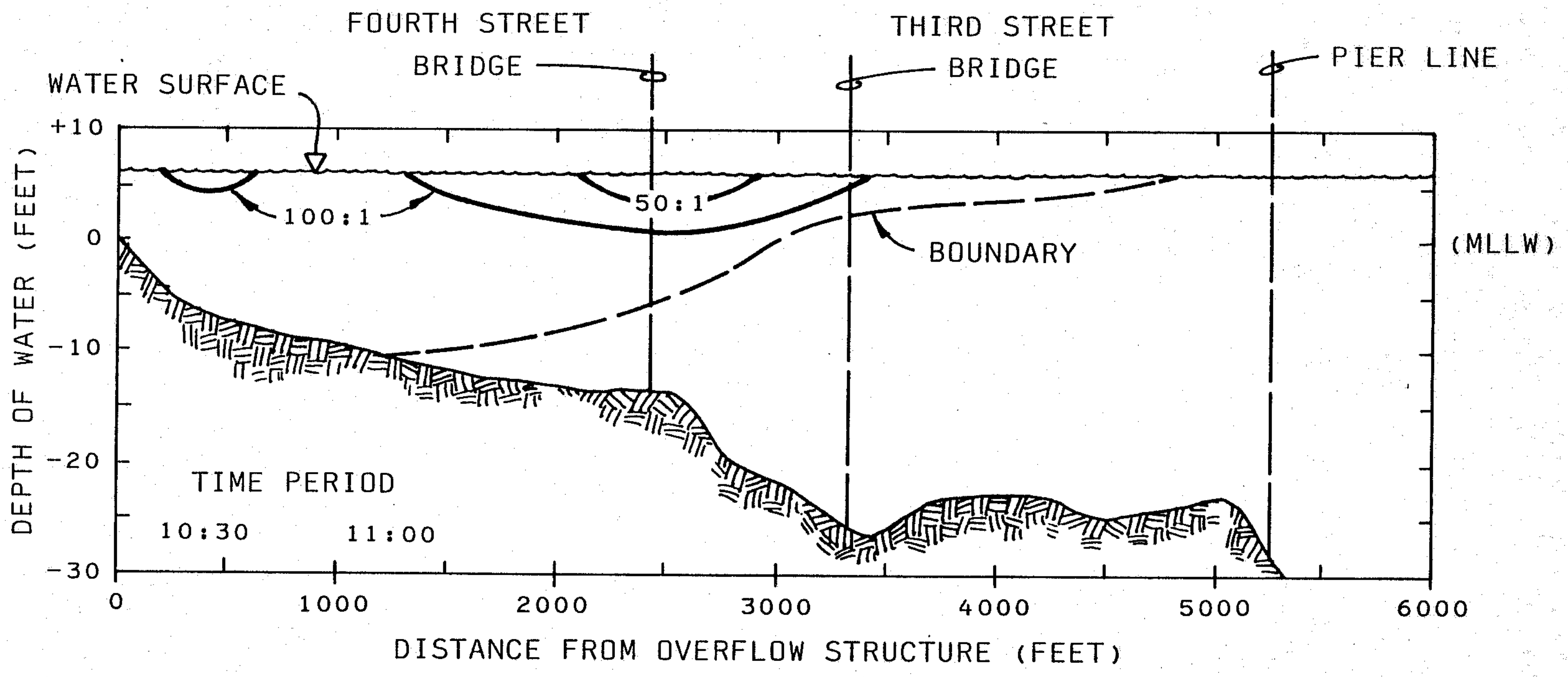
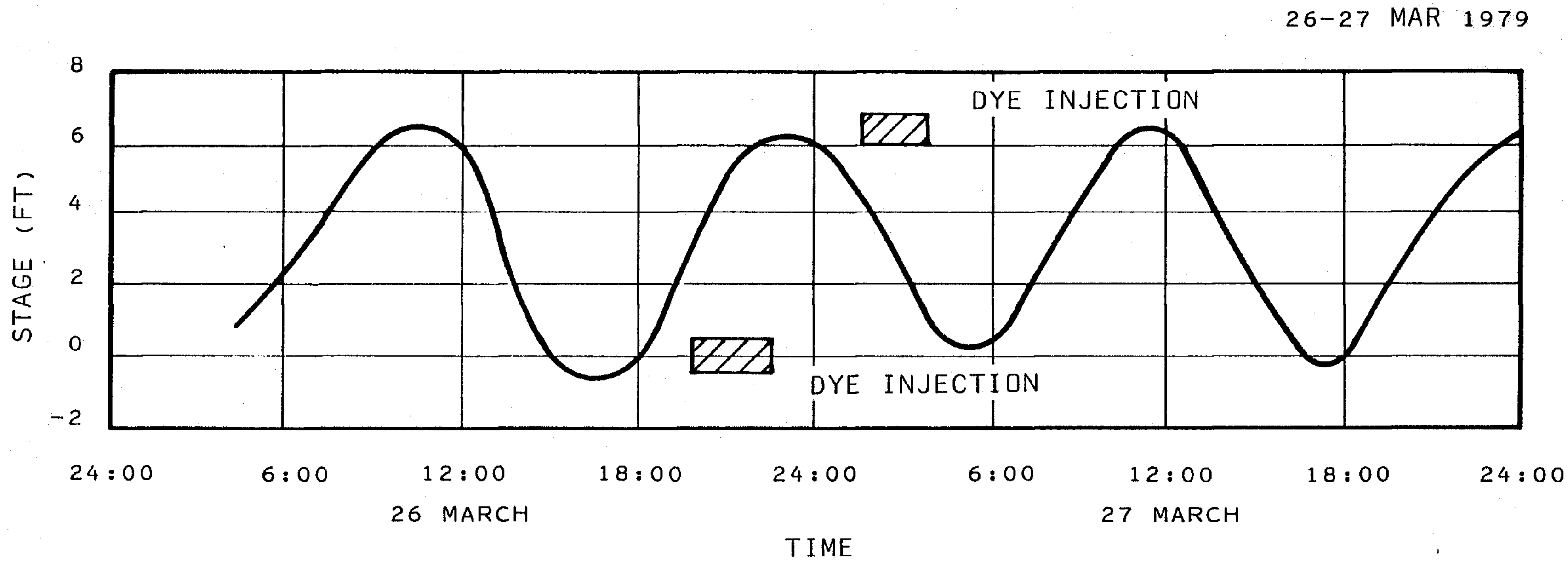


FIGURE III-14 (CONTINUED)
CHANNEL OVERFLOW - DILUTION PROFILES
27 MARCH 1979

CH2M HILL



26 MARCH 1979

TIME	WIND DIRECTION	WIND SPEED (KNOTS)
1:00	WSW	8
4:00	SSE	2
7:00	SSE	6
10:00	SSE	6
13:00	SSE	15
16:00	SSE	13
19:00	SSE	12
22:00	ESE	15

27 MARCH 1979

TIME	WIND DIRECTION	WIND SPEED (KNOTS)
1:00	SSE	20
4:00	SSE	19
7:00	SSE	25
10:00	SSW	21
13:00	SSW	21
16:00	SSW	14
19:00	SSW	7
22:00	SSW	4

FIGURE III - 15
TIDAL STAGE AND WINDS-
CHANNEL OVERFLOW DYE RELEASE

CH2M HILL

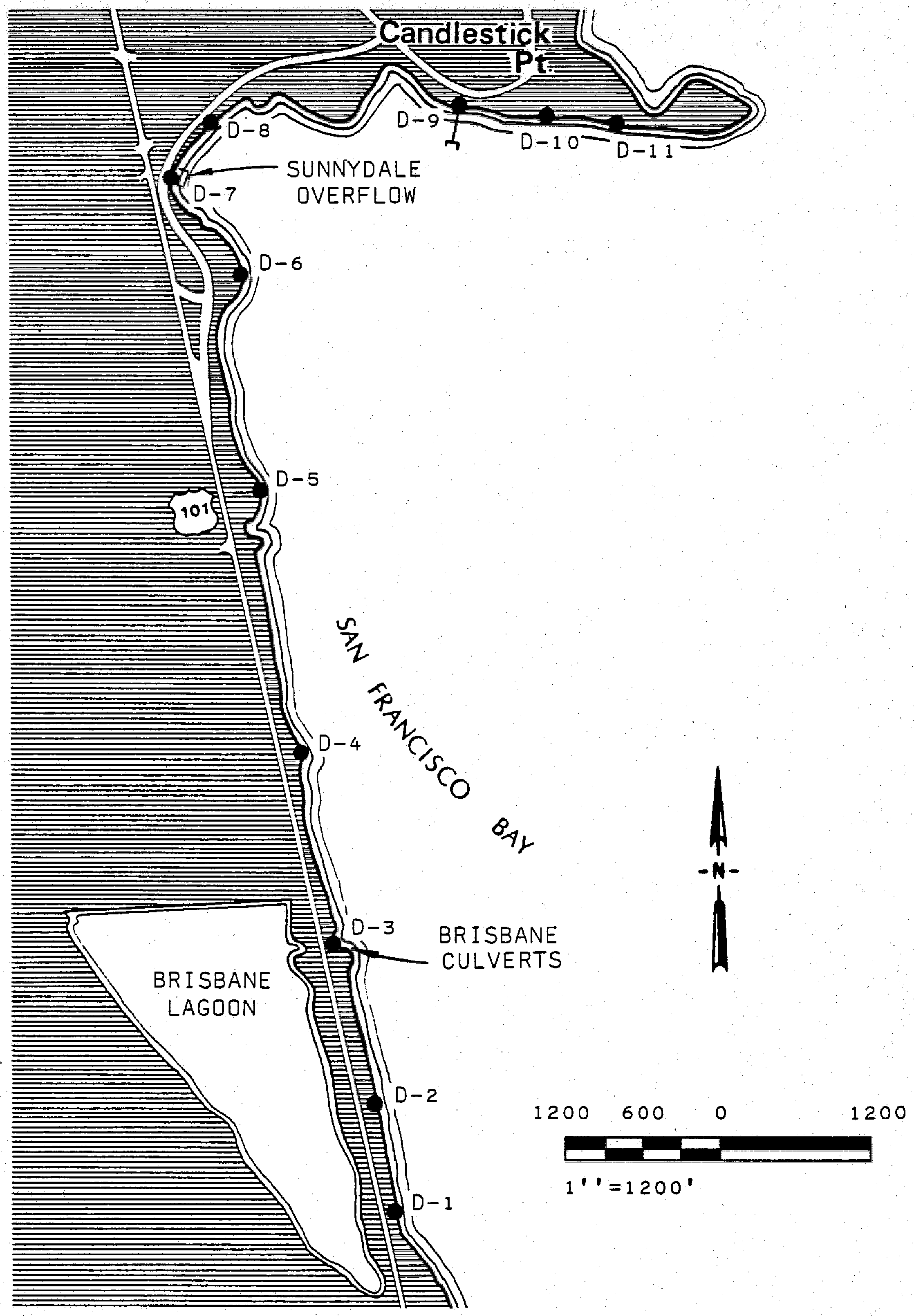
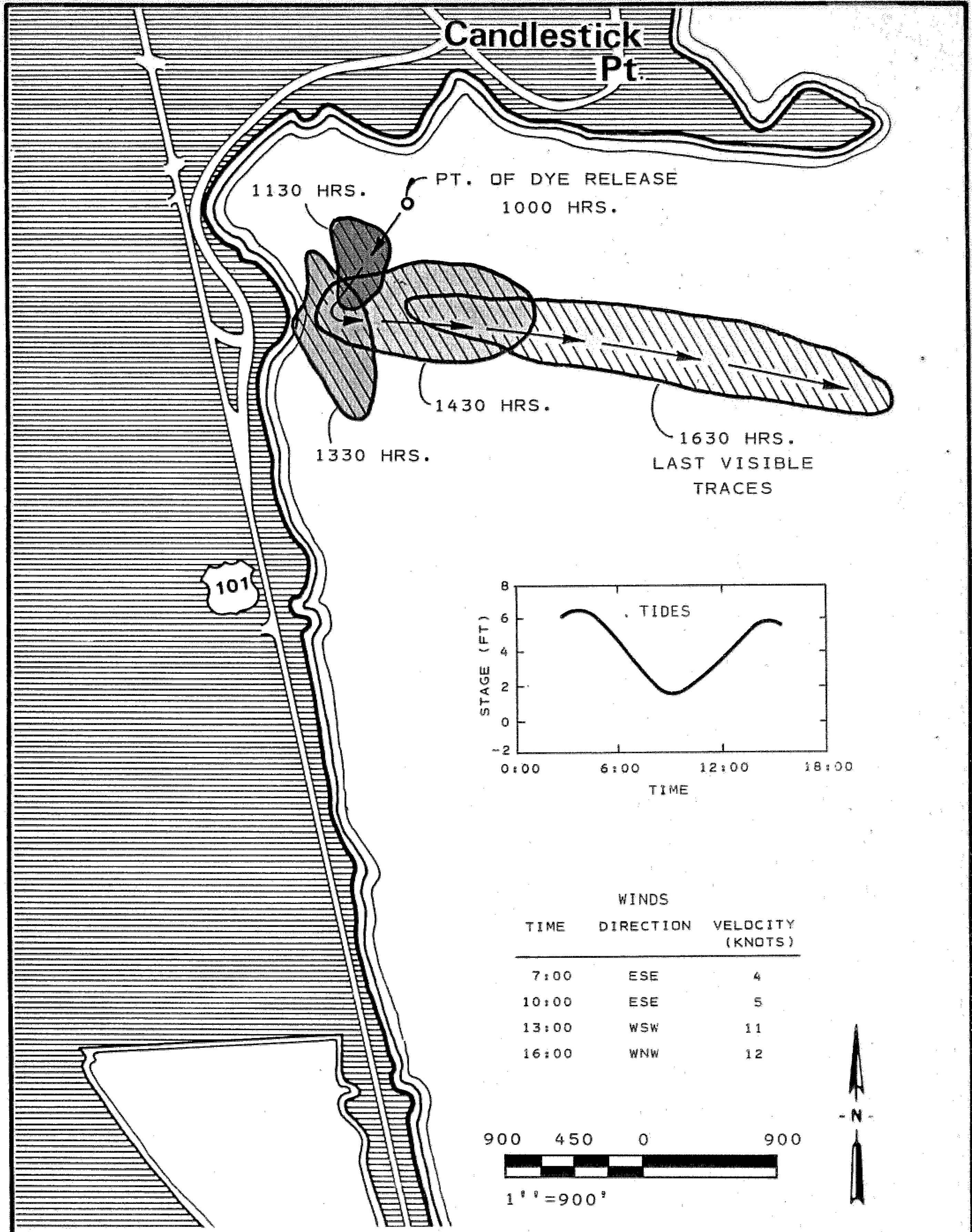


FIGURE III - 16

SHORE STATIONS FOR
SUNNYDALE CONTINUOUS DYE RELEASE
MARCH 26, 27, 1979

CH2M HILL



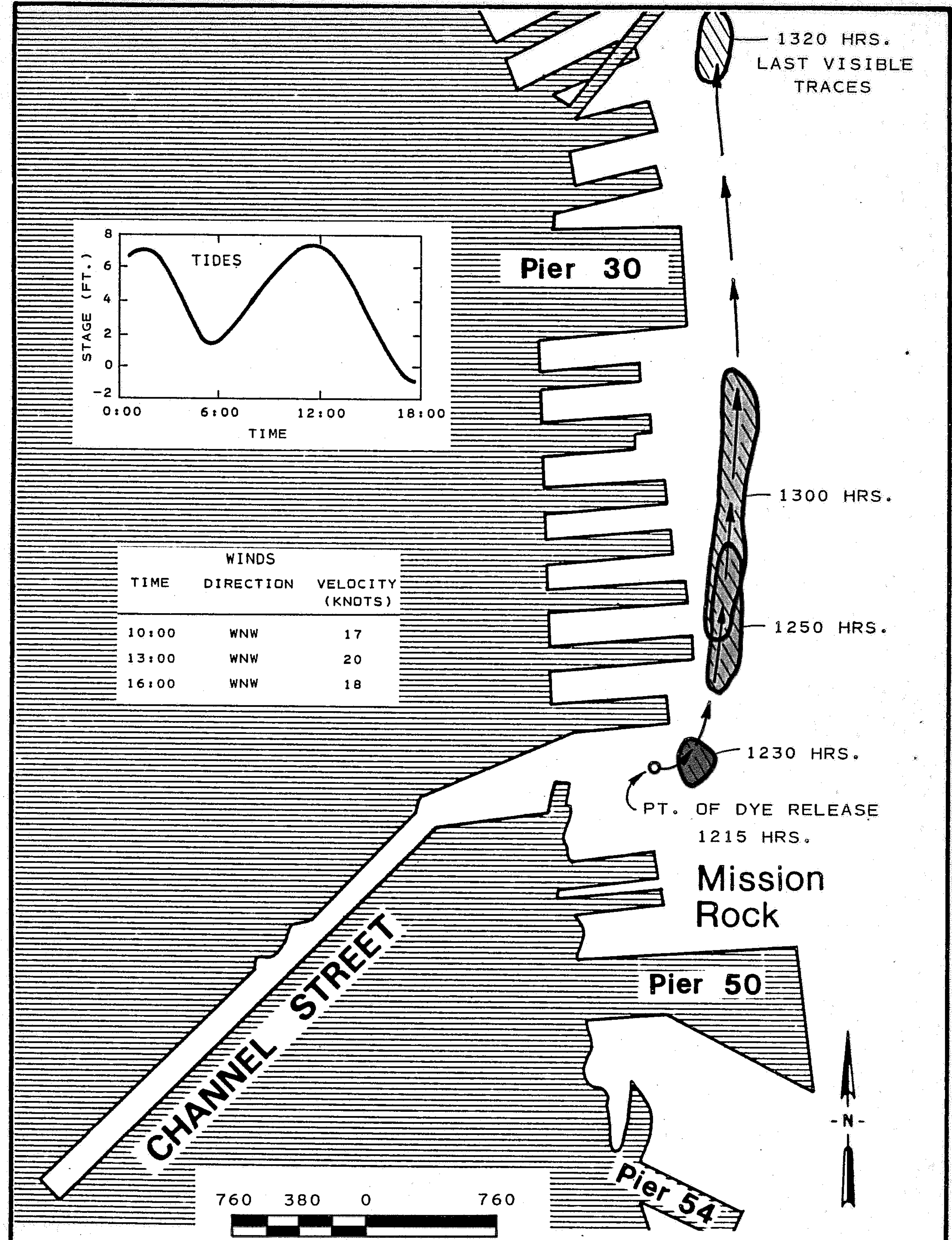
WINDS

TIME	DIRECTION	VELOCITY (KNOTS)
7:00	ESE	4
10:00	ESE	5
13:00	WSW	11
16:00	WNW	12

1 FEB 79

FIGURE III - 17
SUNNYDALE
DYE RELEASE

CH2M HILL



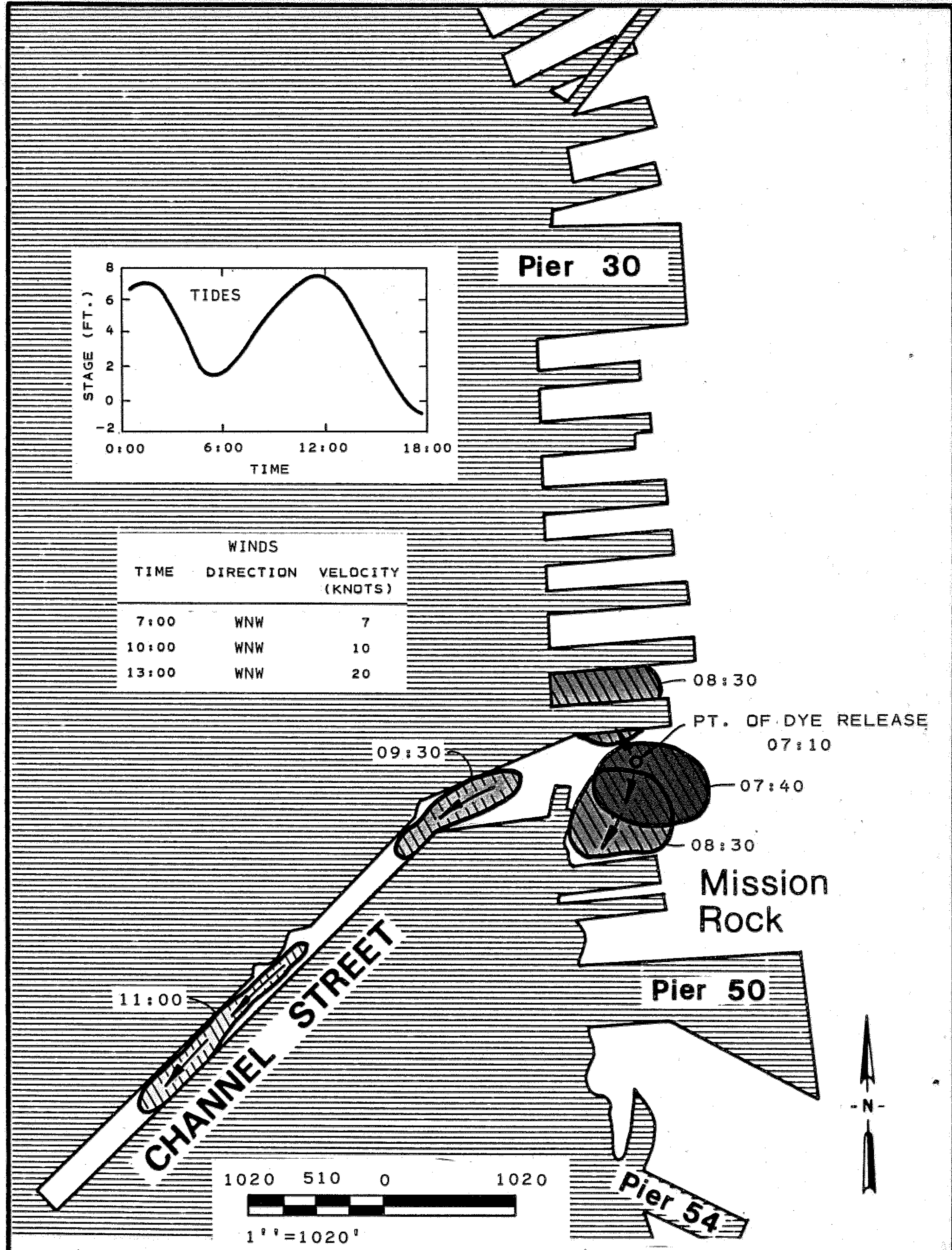
WINDS		
TIME	DIRECTION	VELOCITY (KNOTS)
10:00	WNW	17
13:00	WNW	20
16:00	WNW	18

FIGURE III- 18

FIRST SLUG DYE RELEASE AT CHANNEL

26 FEB 79

CH2M HILL



WINDS

TIME	DIRECTION	VELOCITY (KNOTS)
7:00	WNW	7
10:00	WNW	10
13:00	WNW	20

FIGURE III - 19

SECOND SLUG DYE RELEASE AT CHANNEL

CH2M HILL

27 FEB 79

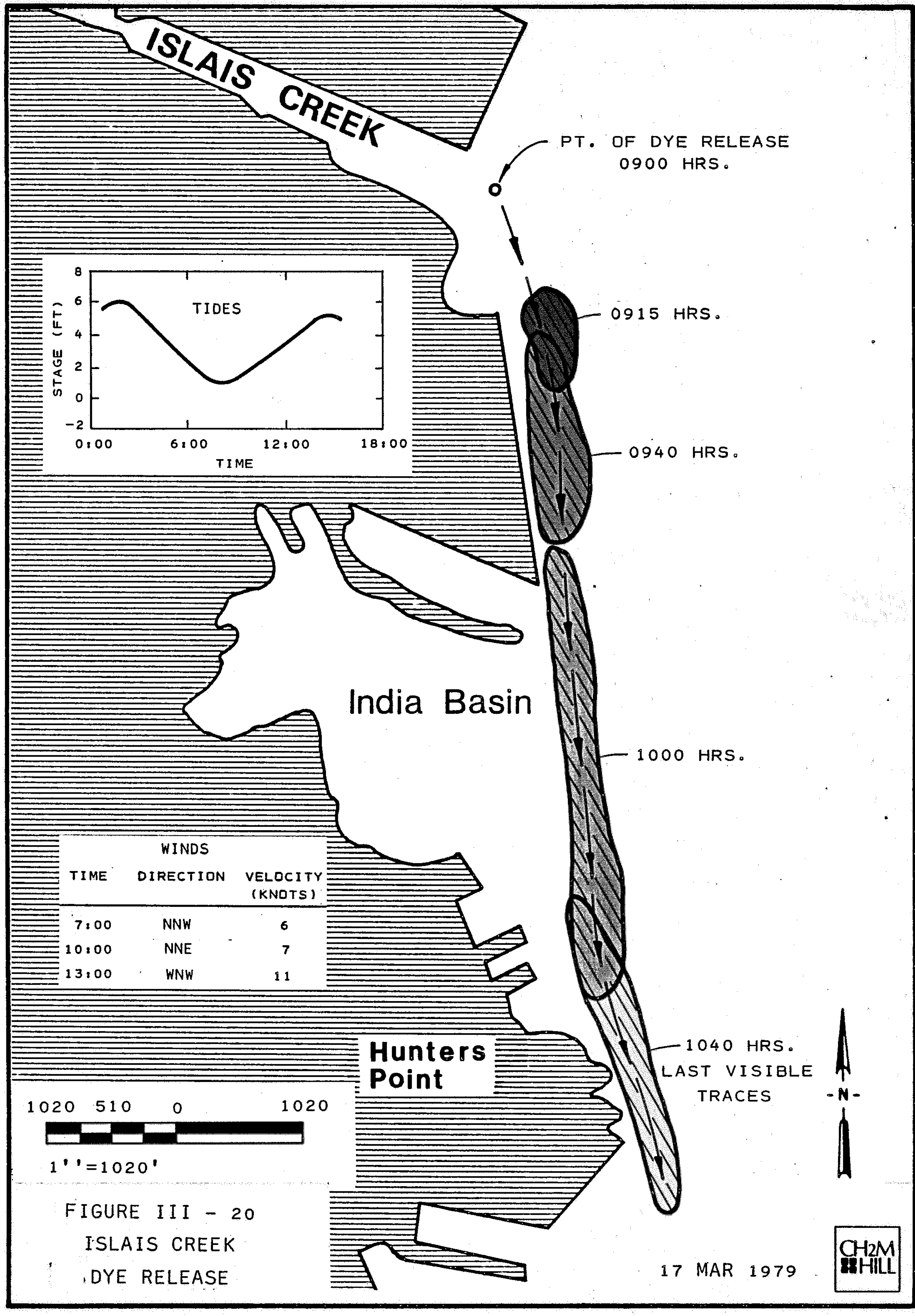


FIGURE III - 20
ISLAIS CREEK
DYE RELEASE

IV. COMBINED SEWER OVERFLOW CHARACTERISTICS

INTRODUCTION

The overflow characteristics were determined during the three storm events by analyzing water samples taken at the overflow structures. The Griffith Street Overflow was sampled by a shore crew which took a grab sample every 6 hours. Automatic samplers were installed at the Sunnydale, Yosemite, Selby, Marin, and Division Overflows.

The sampler intakes were immediately upstream from the overflow gates. When an overflow began, the automatic samplers were activated and were programmed to take composite samples every 6 hours. Each composite sample consisted of equal volume grab samples taken every hour.

At the end of 6 hours, the composite samples were collected and taken to the laboratory for analysis. The samples were tested for conductivity, suspended solids, and total and fecal coliforms. During the third storm event, ammonia concentrations were measured in the overflow. The samplers were turned off when the overflow subsided.

The combined sewer overflow characteristics are tabulated in Appendix B and summarized below.

COLIFORM

The total and fecal coliform levels were measured by the multiple tube technique using three tubes. As anticipated, the coliform concentration in combined sewer overflows was quite variable. The total coliform levels ranged from 3×10^3 MPN/100 ml to 2.4×10^8 MPN/100 ml with most of the values falling in the middle of this range. The coliform levels for the second storm were generally lower than for the other storms.

Fecal coliforms averaged about 40 percent of the total coliform population. This, too, was highly variable as the fecal coliform levels ranged from less than 1 percent to 100 percent of the total population.

The levels measured at the overflow structures fall within the range reported in a prior study for combined sewage (Ref. 1). Generally, the coliform levels in combined sewage are an order of magnitude below the coliform levels in sanitary sewage.

SUSPENDED SOLIDS

The total suspended solids ranged from 8 to 1,440 mg/l. Ninety percent of the measurements were under 150 mg/l. A comparison was made to dry weather, suspended solids levels from data in a 1977 CH2M HILL report (Ref. 2). The 1977 report lists the 1970 to 1976 average dry weather influent suspended solids level as 280 mg/l and the 1970-1976 average influent wet weather level as 233 mg/l to the Southeast Plant.

A wet-weather wastewater characterization report done by Metcalf and Eddy in 1978 (Ref. 3) notes an influent flushing effect during rain storms. It appeared that the suspended solids level first peaked sharply as inert solids were flushed from the sewers by the rainwater and then were diluted by the runoff. This flushing peak was generally not seen at the overflow structures during the first two storms. The peak may have been flattened due to the manner in which the samples were composited. During the third storm, sharp peaks of over 1,000 mg/l appeared at the Sunnydale and Yosemite overflows. However, this peak was not in evidence at the other overflow structures.

SALINITY

The salinity of the combined sewer overflows was calculated by converting the measured conductivity of the samples to salinity expressed in parts per thousand (ppt). From Metcalf and Eddy's Wet-weather Wastewater Characterization Report (Ref. 3), the wet-weather influent to the Southeast Plant had an average salinity of 5 ppt. The samples taken from the overflow usually had salinities of less than 1 ppt.

At times the salinity of the samples was very high, reaching from 18 to 25 ppt. This may have been caused by wave action flooding the sampler intake during the sampling period or from intruded salt water present in the sewers.

The salinity of the Bay varies according to the tides, but it is usually between 20 and 30 ppt. Because the salinity of the overflow is so much lower, the waste field essentially floats on the surface of the Bay for a time. The salinity gradient between the waste field and the underlying Bay water serves as one method of tracing the extent of the combined sewer overflow in the Bay.

AMMONIA

During the third storm event, triplicate grab samples were collected at the Division, Marin, Selby and Yosemite overflow structures for ammonia. The results are summarized in Table

IV-1. Ammonia concentrations were between 1 and 2 mg/l (as N) at Division and .3 to .8 mg/l at Yosemite. The ammonia concentrations at Marin and Selby were more variable and ranged from .6 to 5 mg/l. Typical concentrations in raw sewage are 15 to 25 mg/l. Typical values in Central San Francisco Bay have been reported as .1 to .5 mg/l (Ref. 4).

SUMMARY

The results from the samples at the overflow structures give a characterization of the combined overflows which is supported by previous studies. The total coliform count varied from 3.3×10^3 MPN/100 ml to 2.4×10^8 MPN/100 ml. Suspended solids levels were generally under 100 mg/l. There was inconclusive evidence of a suspended solids peak (first flush effect) due to the manner in which samples were composited. The salinity of the combined sewage was generally less than 1 ppt.

References

1. Engineering Science, "Dissolved Air Flotation Study," July 1971.

2. CH2M HILL, Sanitary & Hydraulic Status Report at Start of Final Design, Southwest Ocean Outfall Project, December 1977.

3. Metcalf and Eddy, Wet-Weather Wastewater Characterization, December 1978.

4. SWRCB, Comprehensive Study of San Francisco Bay, Publication 42, 1971.

TABLE IV-1

AMMONIA CONCENTRATION IN COMBINED SEWER OVERFLOWS

Location	Time* (Hours)	Ammonia Concentration (mg/l N)			
Division Overflow	0	1.1,	1.0,	.9	$\bar{x}$ = 1.45
	19	2.0,	1.3,	1.3	
	21	1.0,	1.2,	1.4	s = 0.47
	29	2.1,	1.9,	2.2	
Selby Overflow	17	5.6,	4.7,	4.0	$\bar{x}$ 2.7
	22	.6,	.7,	.6	s = 2.3
Marin Overflow	0	.6,	.6,	.6	$\bar{x}$ = 1.62
	27	2.7,	2.5,	2.7	s = 1.12
Yosemite Overflow	0	.4,	.5,	.4	$\bar{x}$ = 0.51
	16	.3,	.4,	.3	
	26	.7,	.8,	.8	s = 0.20

Overall $\bar{x}$ = 1.45

*Time is measured from initiation of the overflow event. Overflows occurred periodically during the sampling period.

V. IMPACTS OF COMBINED SEWER OVERFLOWS ON WATER QUALITY

INTRODUCTION

An extensive water quality monitoring program was performed during this project. Offshore and nearshore grab samples were collected before, during and after three overflow events to determine water quality characteristics. There were 15 offshore stations and eight nearshore stations (Figure I-1 and Table I-1). On the first 2 days of the overflow event, samples were collected at each offshore and nearshore station every quarter tidal cycle at slack water. On the following 3 days, samples were collected at one high and one low slack water condition during daylight hours. Each water sample was analyzed for total and fecal coliforms, suspended solids and conductivity. When water depths were greater than 15 feet, samples were collected 2 feet below the surface and at 6 feet above the bottom. Vertical profiles for pH, dissolved oxygen, temperature and conductivity were also obtained at these stations. When water depths were less than 15 feet, samples were collected 2 feet below the surface. Conductivity measurements were later converted to salinity. Offshore and nearshore water quality data from the three surveys are tabulated in Appendices C and D respectively.

Offshore Stations B1, B8, and B11 were the most distant from any overflows and give an indication of Bay background conditions. The other stations are grouped into a series of transects associated with each of the four combined sewer overflows (CSO's) studied: Stations S3, S2, and S1 with Sunnydale; Stations B4, B3, and B2 with Yosemite; Stations S5, S6, B7, and B6 with Islais Creek; and Stations S7, S8, B10 and B9 with Channel (Mission Creek). The extent and effect of sewage field movement could be followed through the results of the samples taken along these transects.

Water quality impacts of CSO's were mainly confined to nearshore areas, particularly within Mission (Channel) and Islais Creek. Offshore effects were minimal, and generally could not be directly attributable to the CSO's. Most impacts at offshore stations were attributable to general rainstorm effects. Typical profiles along the Channel, Islais and Yosemite transects are shown in Figures V-1 to V-3. The water quality impacts are discussed below.

SALINITY

Combined sewer overflows had a noticeable impact on salinity measurements. Each storm resulted in strong salinity stratification in nearshore areas within the upper 3-6 feet of water. Offshore, more mild salinity gradients were noted. The effects at offshore stations cannot be directly attributable to CSO's, since the pattern was observed in areas where CSO wastefields were unlikely to extend.

During peak overflow periods, salinity gradients may be very marked, with surface salinities approximately 1 percent of the underlying Bay water salinity. These extremely strong salinity gradients are contained in the upper 3-6 feet of water in Channel and Islais Creeks. Offshore, salinity gradients are gradual and extend through 10 or more feet. Vertical contours illustrating these salinity changes during the CSO event are provided in Appendix A. The salinity gradients are rather strong except at the Yosemite-Griffith streets overflow area (Double Rock), where the gradients are more mild, generally being a change of only 1 ppt. This more mild change is due to a relatively small volume of wastewater being distributed over a larger surface area of receiving water.

During the first two storms, overflows occurred throughout the 5-day sampling period, obscuring the trends of salinity gradient breakdown. The third storm had overflows only during the first 2 days of sampling. In this storm, salinity gradients at inshore stations returned to normal within approximately 24 hours.

TEMPERATURE

Temperature impacts due to CSO's were found to be minor, with the temperature of the wastefield being determined largely by the temperature of the front causing the precipitation. During the first and third storms, wastefields in Channel and Islais were slightly (at most 1-2°C) warmer than underlying Bay water. During the second storm, the wastefield was generally cooler than Bay water, although occasionally the wastefield was the same temperature as deeper Bay water but was cooler than water of intermediate depth. This was due to downward displacement of the Bay water which had been warmed by the sun before the overflow.

Maximum differences between Bay water and wastefield temperatures were seen during periods of maximum salinity differences but did not exceed 3°C in any of the storms. The temperature profiles return to normal within approximately 24 hours.

SUSPENDED SOLIDS

Suspended solids concentrations were not directly related to the timing or volume of CSO's. Levels fluctuated dramatically at inshore stations. Wind and tide generated turbulence apparently dominates the dynamics of suspended solids during overflows.

DISSOLVED OXYGEN

Combined sewer overflows had a minimal impact on dissolved oxygen profiles for the majority of the areas and storms studied. Dissolved oxygen concentrations in the wastefield were slightly different from that of underlying Bay water. Saturations were typically between 70 percent and 90 percent, though the values did range between 50 and 100 percent. At times the saturation levels of the wastefield differed 10 percent to 15 percent from the underlying Bay water, although this difference amounted to less than 2 mg/l.

On one occasion, a distinct dissolved oxygen sag occurred in Islais Creek. The sag was restricted to the wastefield. The lowest saturation values were observed near the CSO structures. This suggests that the sources of the alteration were the Marin and Selby outfalls. The D.O. concentration at Station 5 (upper end of the creek) at 15:40 hours was 0 percent saturation at the surface, 53 percent saturation (5.4 ppm) at 2 feet, and 78 percent saturation (8.0 ppm) at the bottom. The D.O. concentration at Station 6 (at the Third Street bridge) at 22:00 hours was 30 percent saturation at the surface (3.0 ppm), while the bottom waters were 89 percent saturated. These low D.O. values rose slowly, reaching 56 percent saturation at 14:00 hours on the 29th of March.

Mission Creek (Channel) often has low oxygen content throughout the water column with lowest values at S7 (the upper end). These low values are not directly attributable to the CSO since wastefield dissolved oxygen values are often above those of the underlying water. CSO's may indirectly contribute to these low D.O. levels through oxidation of previously settled material. D.O. concentrations at S8 (Third Street bridge) were normal suggesting that these low background D.O. levels persisted only at the innermost end of the channel.

There was no indication that offshore oxygen was affected by the CSO's. Values were typical of the Bay, ranging from 80 percent to 100 percent saturation.

pH

Combined sewer overflows did not have a major impact on pH. Normally, the pH of the wastefield was in the 7's while Bay waters were in the high 7's to low 8's. On one occasion (February 13), a pH above 9 was observed in Islais Creek.

This occurred at the same time as the dissolved oxygen sag previously discussed. At 06:30 on that day, a pH value of 7.9 was recorded at the surface. By 15:30 the pH had increased to 9.6 while underlying waters had a pH of 8.1. The pH had returned to normal by 17:25 on February 14. The same pattern was recorded at both S5 and S6 and the high pH was restricted to the wastefield layer. An apparent episode of industrial waste dumping would explain both the pH and D.O. changes found in Islais Creek.

BACTERIAL DIE-OFF

The disappearance of coliform bacteria after discharge into San Francisco Bay is due to several different factors including dilution and dispersion, predation, sedimentation, and mortality. It appears from the results of ocean experiments that mortality is usually the most important of these factors (Mitchell and Chamberlin, In Press). For this reason a bacterial die-off study was conducted to determine the mortality rate of coliform bacteria in Bay water. A detailed discussion of this die-off study is contained in Appendix E.

The results of bacterial reduction studies are often expressed as T_{90} values. The T_{90} is the time it takes for 90 percent of the bacteria present to disappear. The value of T_{90} found in the bag experiments is approximately 36 hours for both total and fecal coliforms.

The reduction rate measured in the bags should be considerably less than that which occurs in the Bay itself, because neither dilution nor sedimentation occur in the bags. The results of the field measurements of coliforms during the third storm can be used to test this hypothesis. The in-field reduction of bacteria from three stations in Channel and Islais was greater than that in the bags. The greater disappearance rate is, of course, due to dilution and sedimentation. The in-field T_{90} value is approximately 24 hours for both total and fecal coliforms.

COLIFORMS

The background pre-overflow levels of total coliforms ranged from 200-500 MPN/100 ml while fecal coliform levels were 30-200 MPN/100 ml. By comparison, dry weather total coliform levels reported for 1978 were usually less than 100 MPN/100 ml while fecal coliform levels were less than 50 MPN/100 ml. J.B. Gilbert and Associates (Ref. 1) estimated an average background total coliform concentration of 60 MPN/100 ml based on a review of available literature.

Bacteriological standards have been established by the Regional Water Quality Control Board for San Francisco Bay. For water-contact recreation there are two standards. The first, contained in the Basin Plan, states: Total coliform concentration, based on a minimum of not less than five consecutive samples, shall not exceed a median value of 240 MPN/100 ml, nor shall any sample exceed a total coliform concentration of 10,000 MPN/100 ml. In addition, the fecal coliform concentration shall not exceed a median value of 50 MPN/100 ml, nor shall any sample exceed a maximum fecal coliform concentration of 400 MPN/100 ml. The second standard is from the California Administrative Code and states that not more than 20 percent of samples taken over a 30-day period can have a total coliform concentration greater than 1,000 MPN/100 ml.

The sampling periods for this study were not long enough to determine compliance with the California Administrative Code standard. The standards established in the Basin Plan, however, were exceeded at all stations during the three sampling periods.

The bacteriological standards for waters overlying shellfish beds used for human consumption are: The median total coliform concentration throughout the water column for any 30-day period shall not exceed 70 MPN/100 ml, nor shall more than 10 percent of samples collected during any 30-day period exceed 230 MPN/100 ml. The sampling periods were not long enough to determine compliance with the shellfish standards. The median 5-day total coliform concentration was over 70 MPN/100 ml at all stations during the three sampling periods.

In summary, the coliform levels in the overflow channels are directly related to the occurrence of combined sewer overflows. During overflows the coliform concentration in the channels was three to four orders of magnitude above background levels and in the offshore stations the level was one order of magnitude above background. The coliform levels in the channels reached a 10:1 dilution by the end of the pier line. After the overflow stopped, the bacteria level decreased rapidly. The T_{90} value in the channels, including natural die-off and dilution, was about 24 hours and was lower in the open Bay. Within 2 days following an overflow the coliform concentration in the offshore stations had returned to background levels. The 5-day sampling periods are insufficient to determine compliance with most bacteriological standards. If the background levels noted during the sampling were applied to a 30-day period, however, both the water-contact recreation standard and the shellfish overlying water standard would be exceeded at all stations in the study area.

The coliform levels in Islais and Channel Creeks after an overflow are illustrated in Figure V-4. This figure is based upon data collected during the third storm. Overflows occurred during the first 2 days of this storm sampling period. No overflows occurred during the remaining 3 days. This figure illustrates the reduction in coliform levels after the overflows subsided. It indicates that there is a direct correlation between combined sewer overflows and coliform levels. When there was an overflow, the coliform levels in the channels usually rose by about four orders of magnitude over background levels. When the overflow stopped, the coliform levels began dropping until the next overflow at which time levels rose approximately one order of magnitude and then decreased until the next overflow. The last overflow in the sampling period occurred during the second day. This was followed by a short lag time and then the coliform levels began decreasing rapidly. These decreasing coliform levels can be attributed both to the natural die-off rates and the physical process of dilution and sedimentation. Normal levels are generally found within 48 hours after the last overflow. The T_{90} value is approximately 24 hours in Islais Creek and Channel. In the open Bay the T_{90} value is even smaller mainly due to the increased dispersion and advection.

There was a decreasing coliform gradient moving out from each overflow structure. At the end of the pier line, the initial coliform concentration was diluted by at least 10:1. In the offshore stations, the coliform concentration was generally about 2,000 MPN/100 ml, or one order of magnitude over the measured background level within 2 days. These observations are illustrated spatially and temporally in Figures V-5 through V-7. The coliform distribution during the first part of the storm on March 27 is shown in Figure V-5.

On March 28 (Figure V-6) the coliform levels in Channel and Islais Creek were still high since there had been several small overflows during the day. This effect extended past the mouths of the two channels. Elsewhere, the coliform concentration had dropped to about 900 MPN/100 ml with a few small patches of higher concentration.

On March 30 (Figure V-7), 2 days after the last overflow, the concentration in Channel and Islais Creek was still one order of magnitude above background levels. Compared to the initial combined overflow concentration, the coliforms in the channels were diluted by at least 500:1. The other stations in the study area had returned to background coliform concentrations except for isolated pockets of higher concentrations. Coliform levels inside these sloughs returned to normal within approximately 84 hours.

SUMMARY

The major effects of the combined sewer overflows on water quality are confined to the nearshore stations. Of the five physical parameters tested, salinity levels were most affected by combined sewer overflows. There were strong salinity gradients in the channels of Islais Creek and Channel with gradual gradients present at the pier line. The effects of the overflows on dissolved oxygen levels were minimal although there were isolated instances of oxygen sags in Channel and Islais Creek. The dissolved oxygen levels of the offshore stations were unaffected. Temperature gradients due to the overflows were minimal with a maximum difference of 3°C. Solids could not be directly related to overflow events, but pH and dissolved oxygen can be affected severely by industrial waste dumping.

The coliform levels appeared to be directly related to the times of overflows. When an overflow occurred, the coliform levels near the overflow structures jumped several orders of magnitude above background levels. After an extended overflow the offshore stations were also one order of magnitude above background. Within 2 days the offshore stations returned to background levels with slightly higher concentrations present in the channels. The T_{90} values in the channels, including natural die-off, physical dilution and sedimentation, was about 24 hours. The T_{90} value in the bag experiments was 36 hours.

References

1. J.B. Gilbert & Associates, Effects of Combined Sewer Overflows On Receiving Water Quality, August 1978.

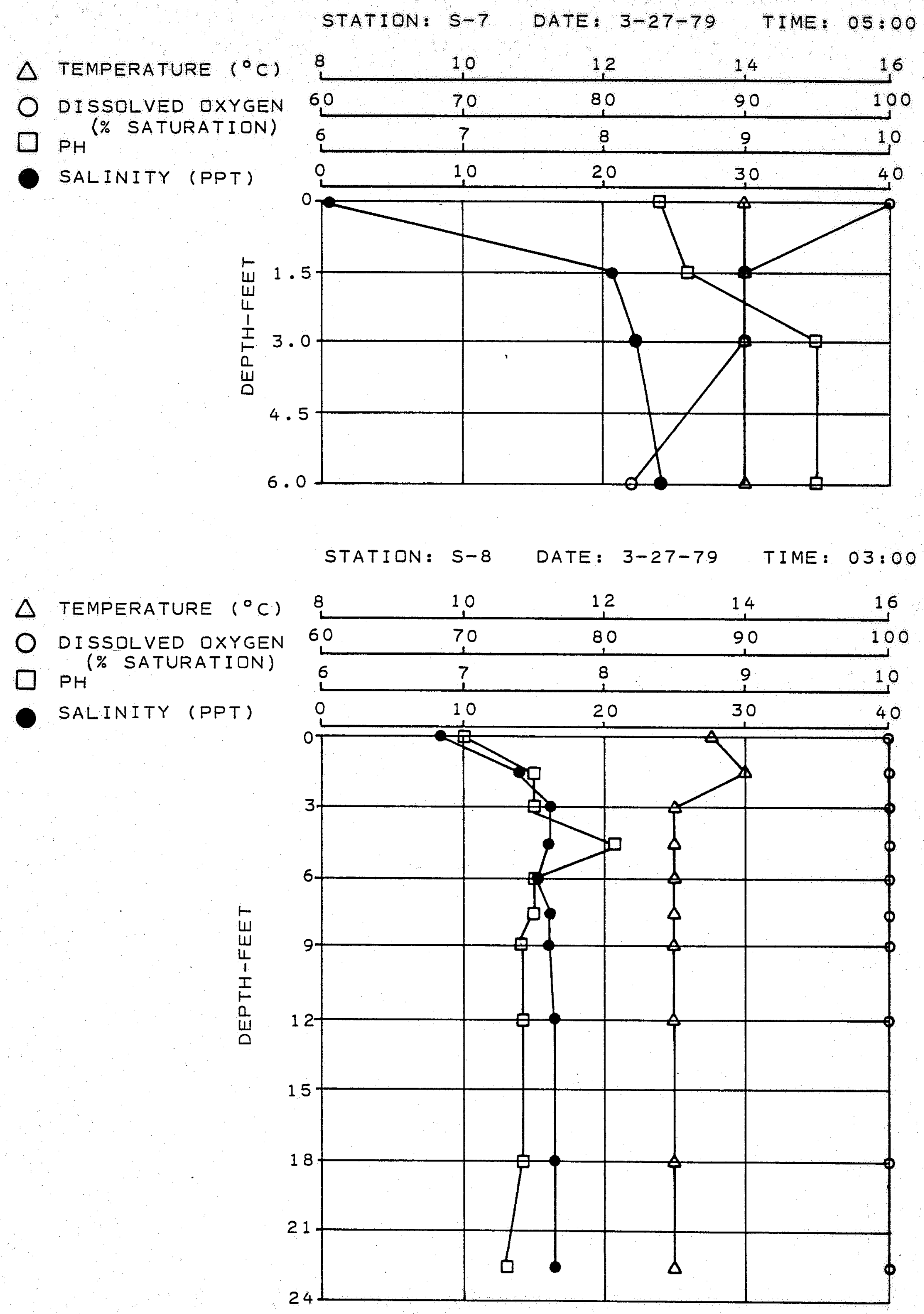
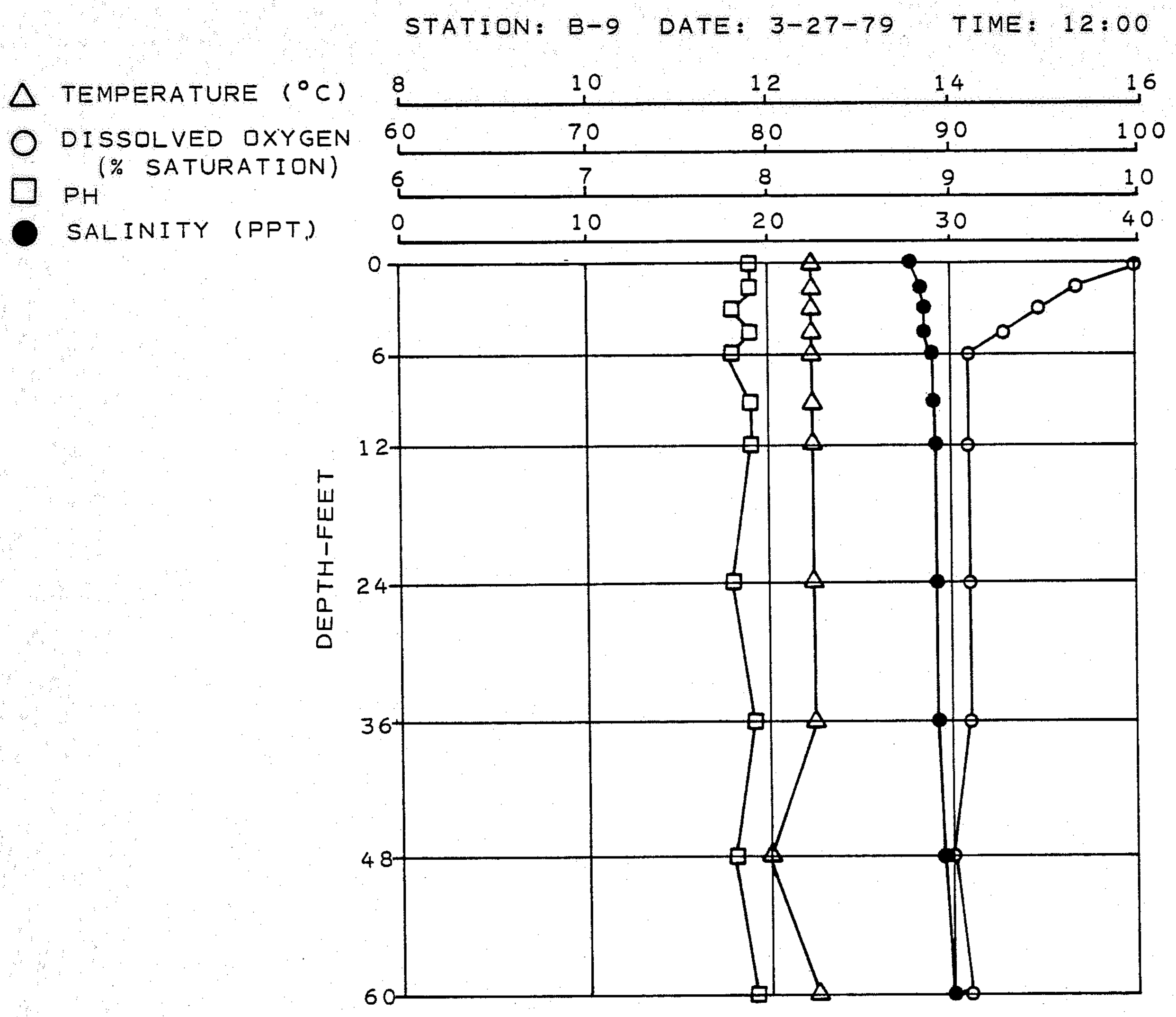


FIGURE V-1

CHANNEL CREEK TRANSECT
WATER QUALITY PROFILES

CH2M HILL



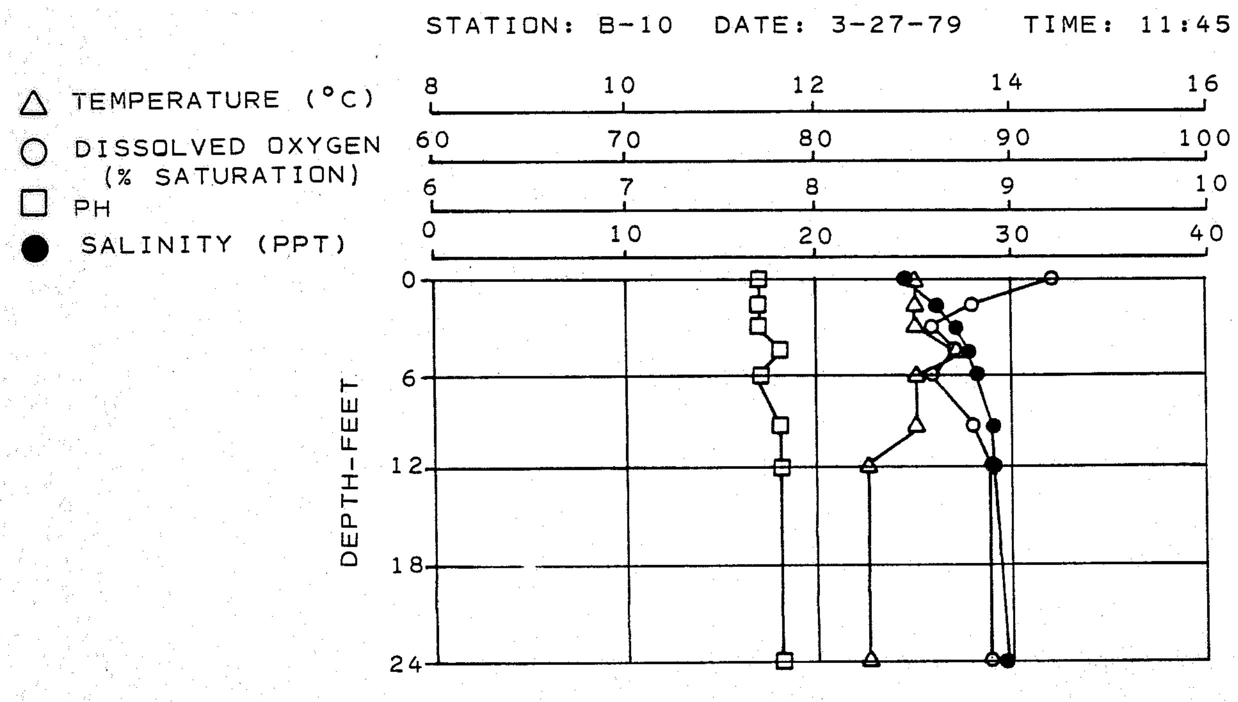
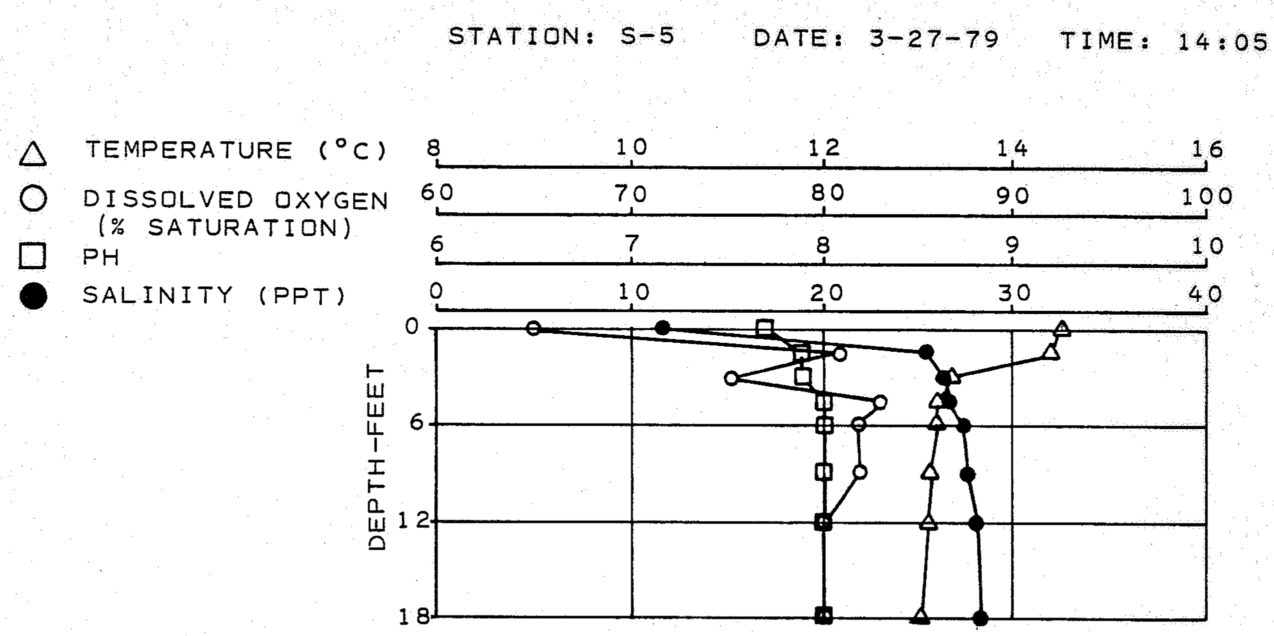


FIGURE V-1

CHANNEL CREEK TRANSECT
WATER QUALITY PROFILES (CON'T.)



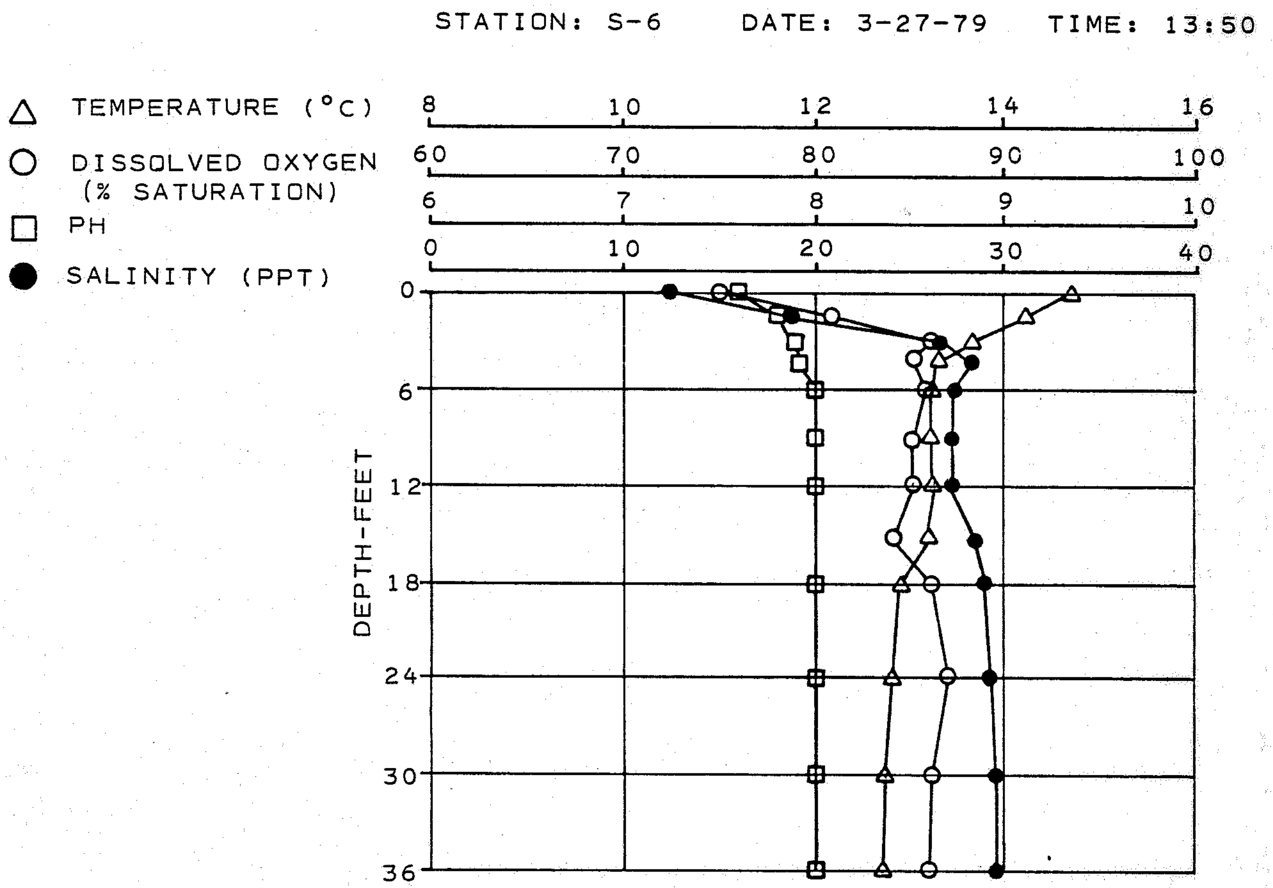
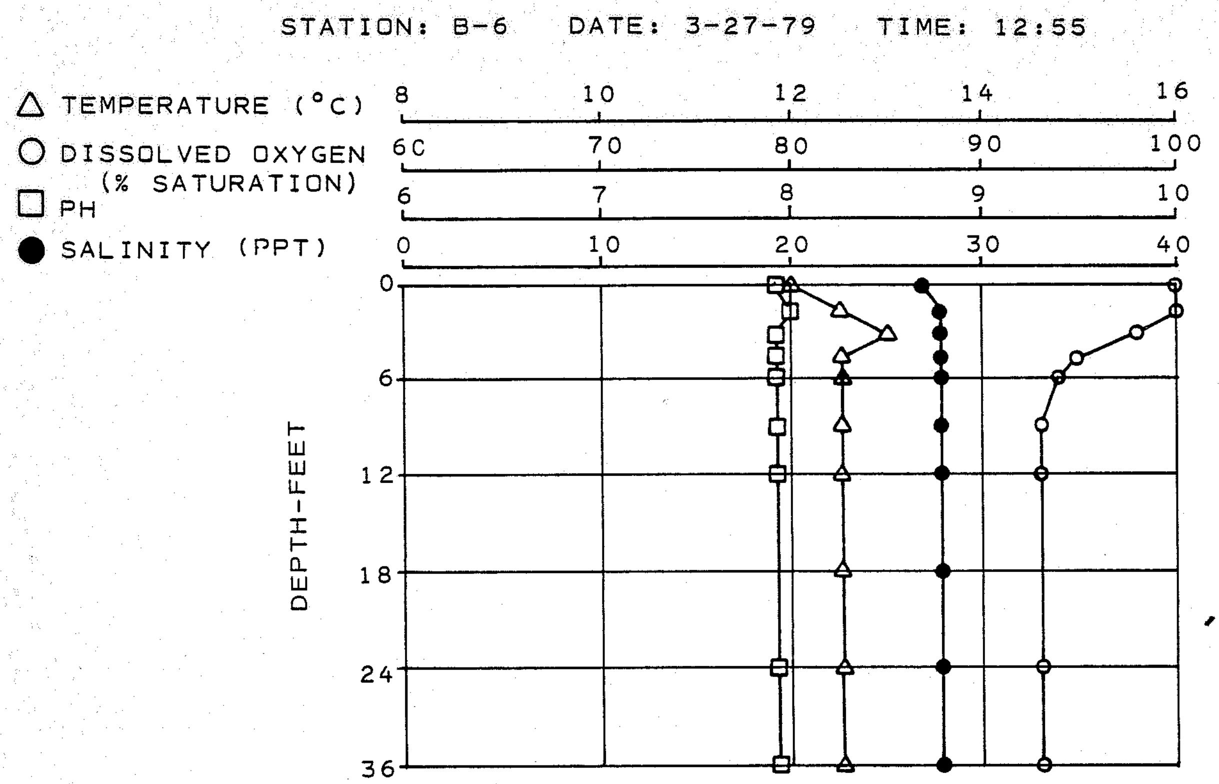


FIGURE V-2

ISLAIS CREEK TRANSECT
WATER QUALITY PROFILES

CH2M HILL



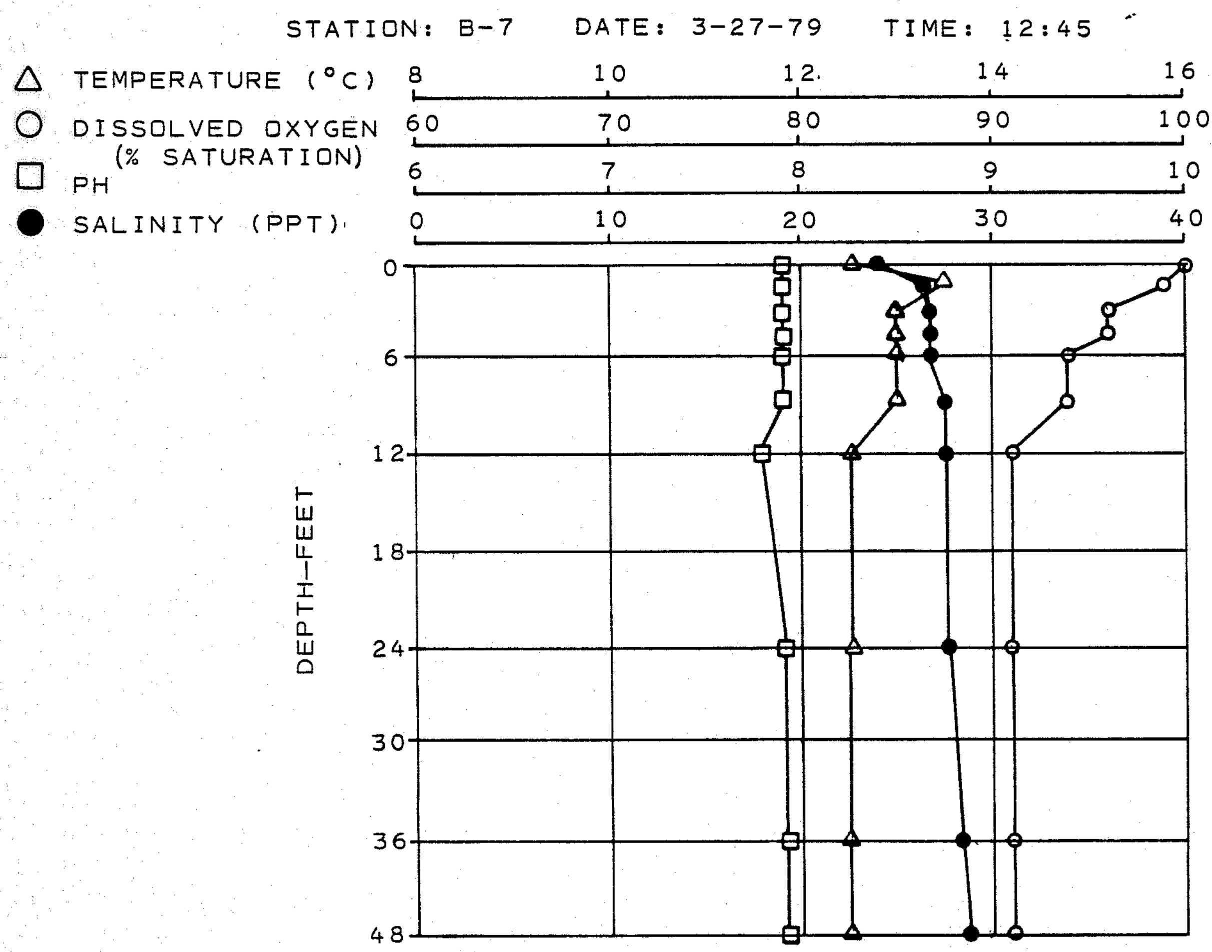


FIGURE V-2

ISLAIS CREEK TRANSECT
WATER QUALITY PROFILES (CON'T.)

CH2M HILL

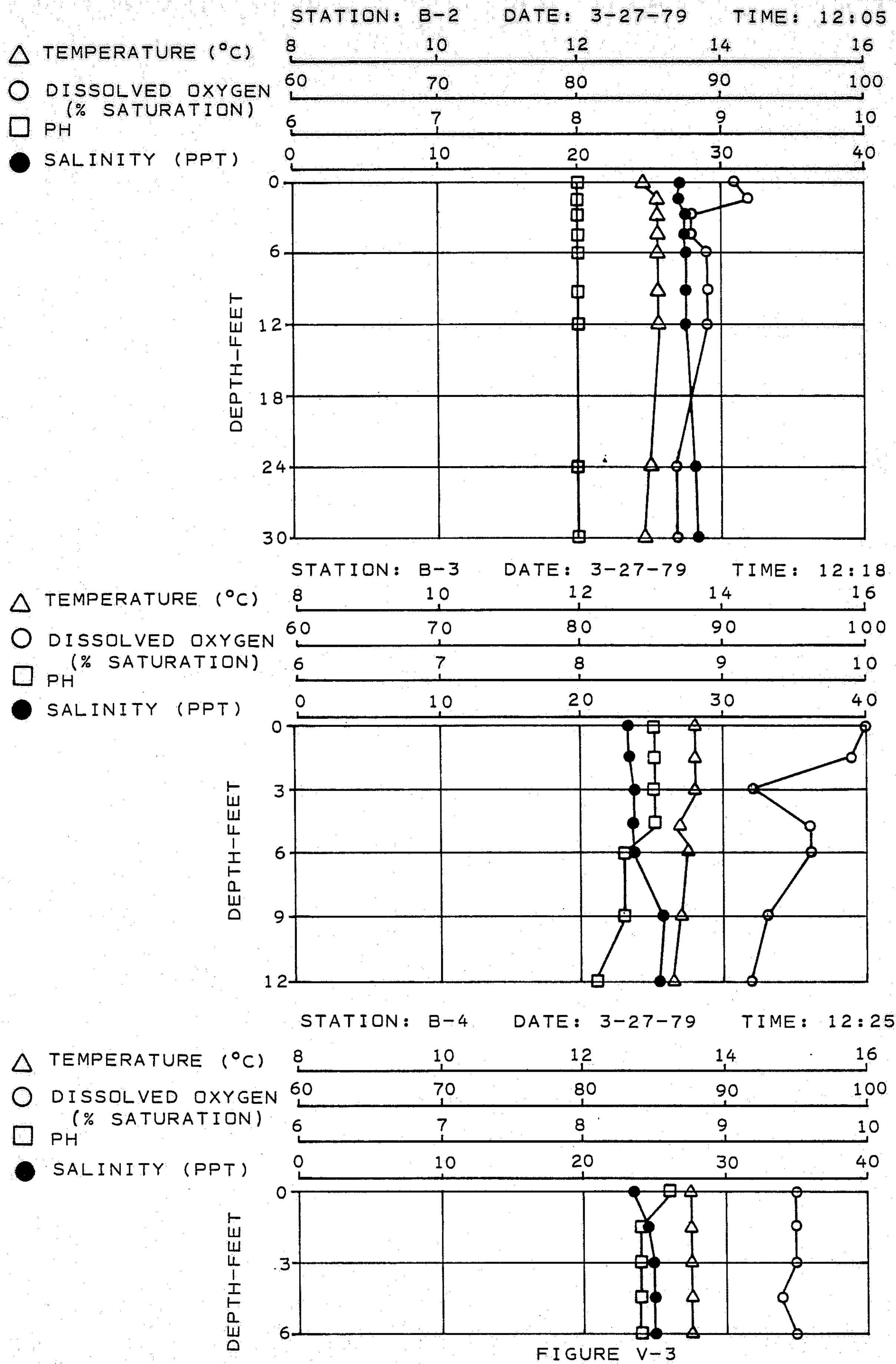


FIGURE V-3

YOSEMITE OUTFALL AREA TRANSECT
WATER QUALITY PROFILES

CH2M HILL

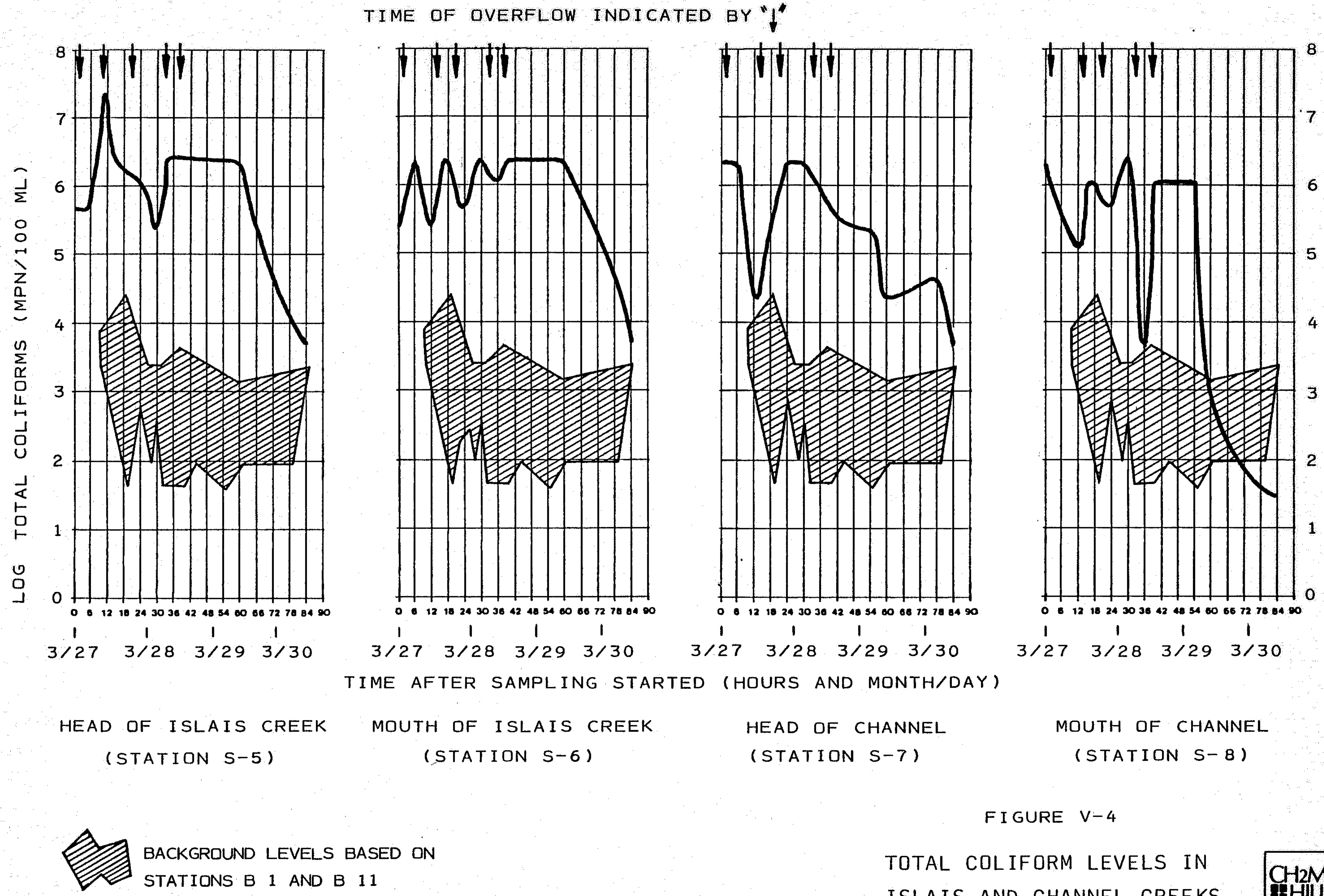


FIGURE V-4

TOTAL COLIFORM LEVELS IN
ISLAIS AND CHANNEL CREEKS

CH2M HILL

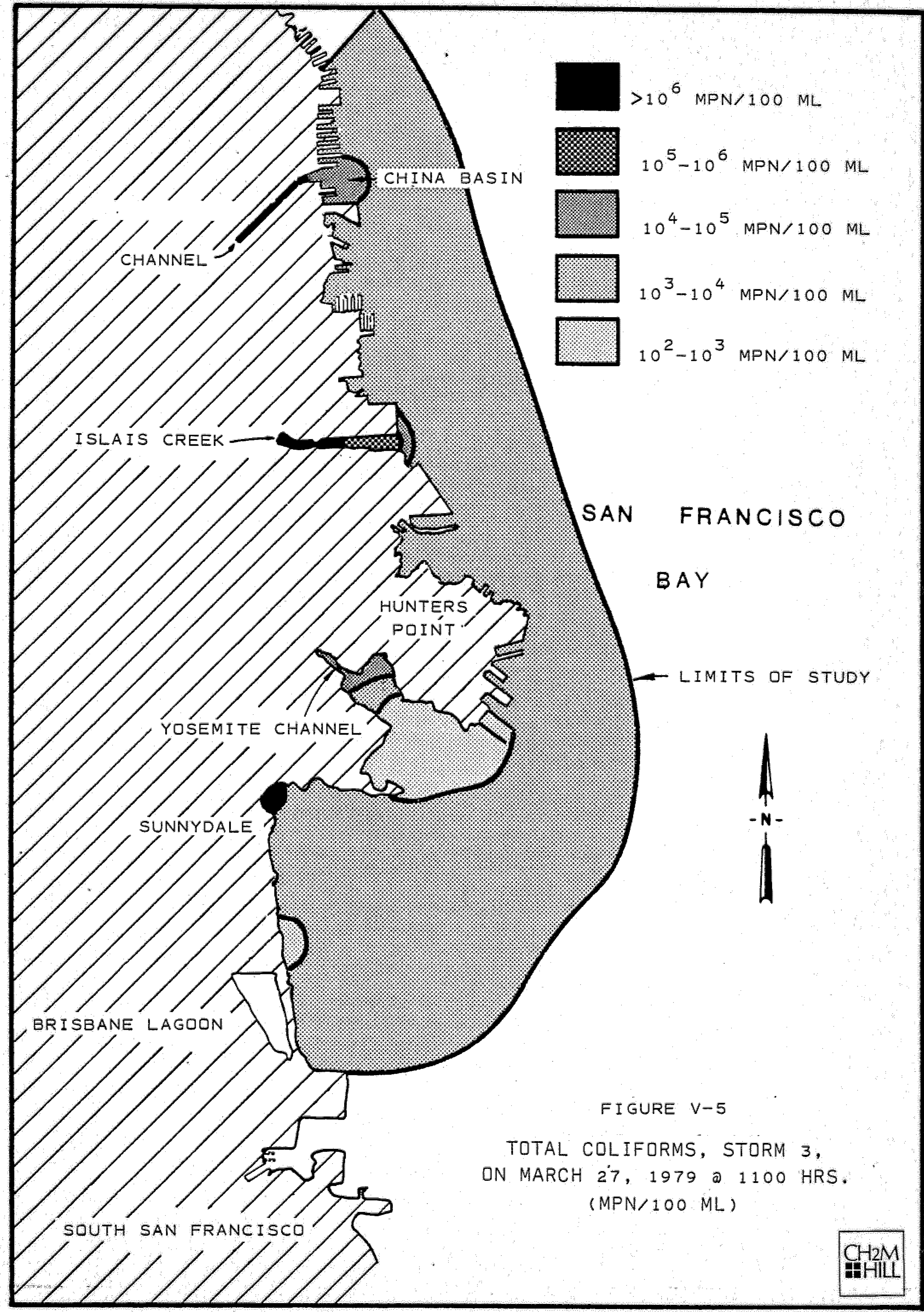


FIGURE V-5

TOTAL COLIFORMS, STORM 3, ON MARCH 27, 1979 @ 1100 HRS. (MPN/100 ML)

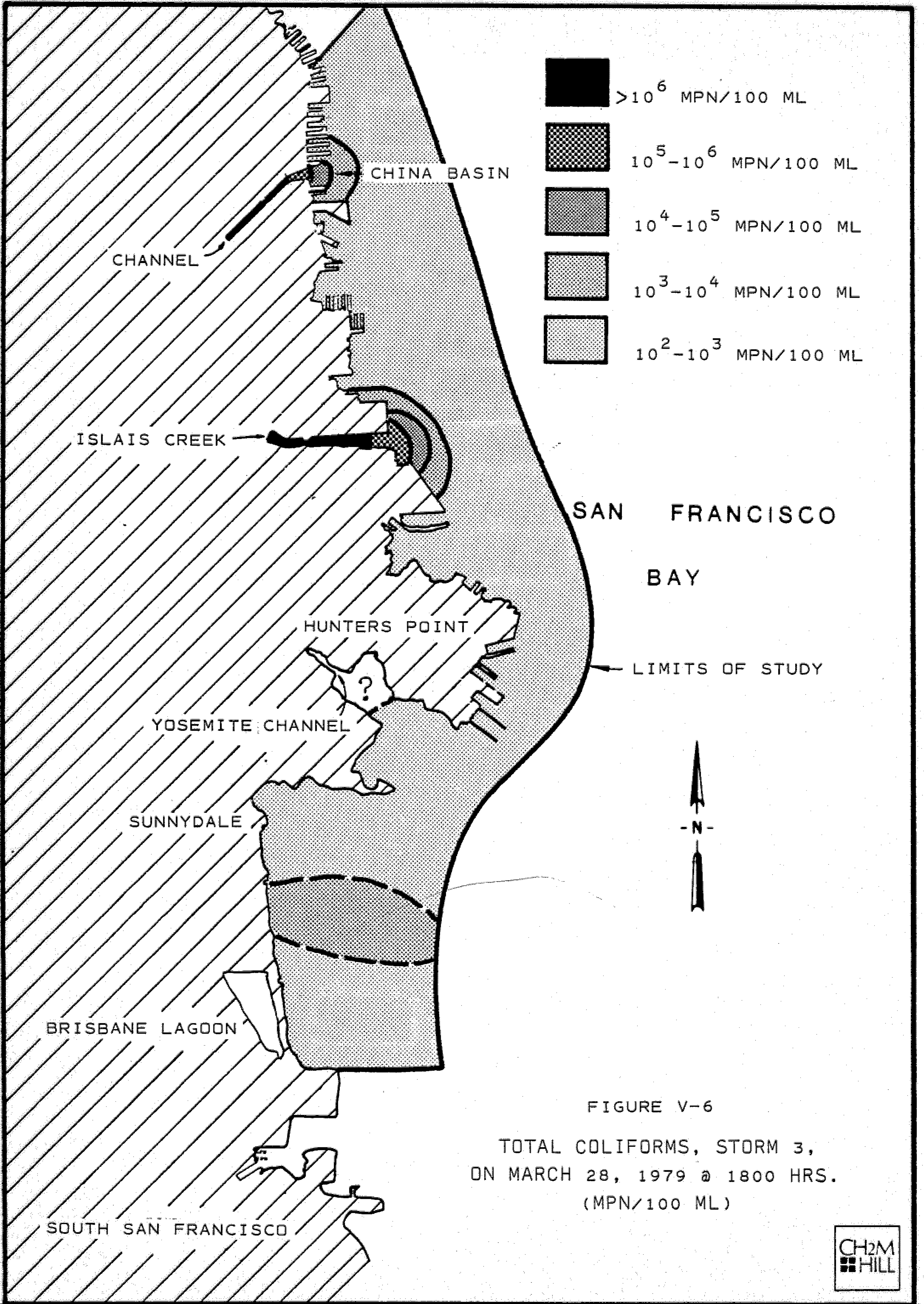


FIGURE V-6

TOTAL COLIFORMS, STORM 3, ON MARCH 28, 1979 @ 1800 HRS. (MPN/100 ML)

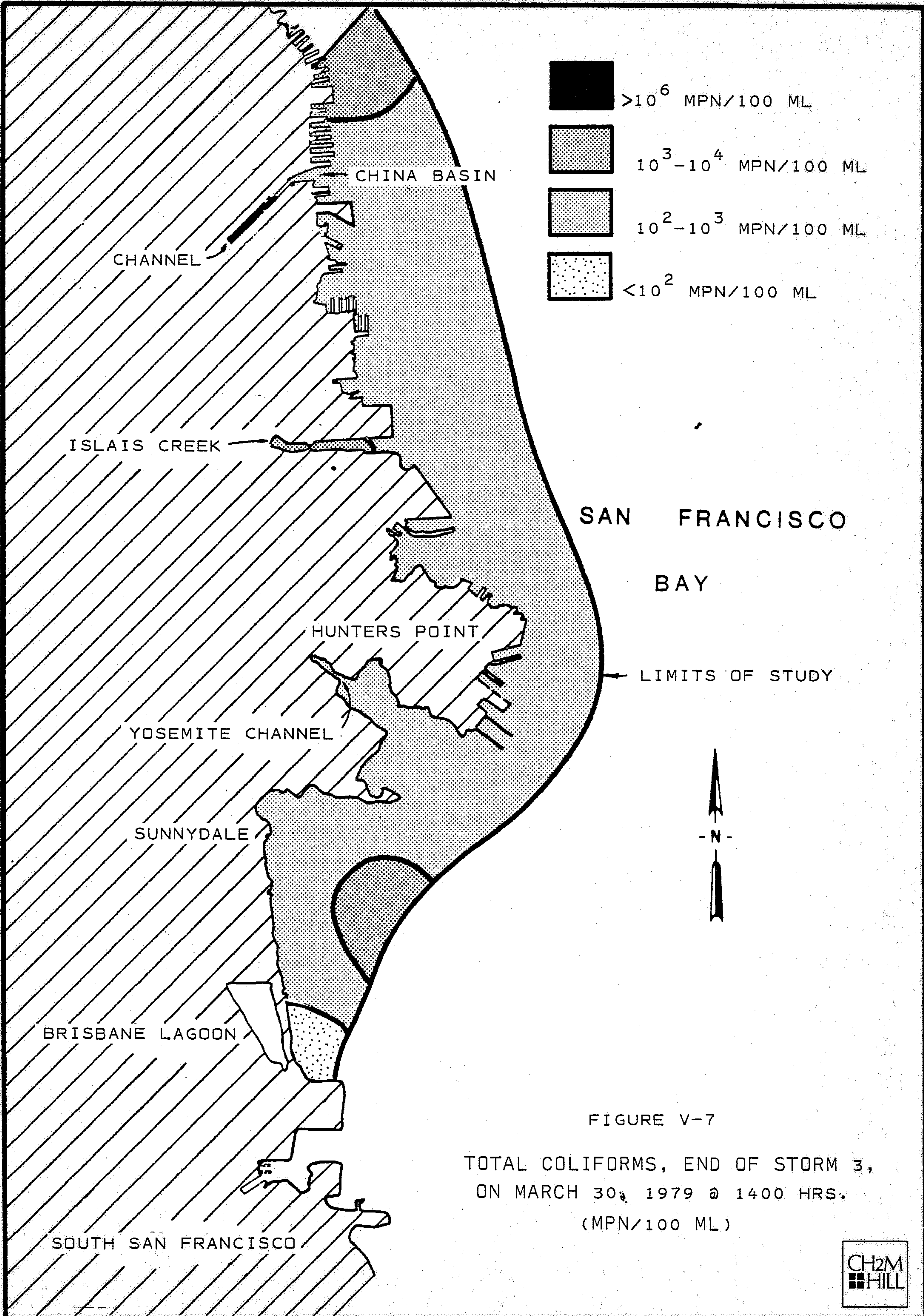


FIGURE V-7

TOTAL COLIFORMS, END OF STORM 3, ON MARCH 30, 1979 @ 1400 HRS. (MPN/100 ML)

VI. IMPACTS OF COMBINED SEWER OVERFLOWS ON THE SEDIMENTS AND BENTHIC INFAUNA

INTRODUCTION

Benthic infaunal organisms integrate transient environmental effects over time and these can be reflected by the species present and their productivity. The physical and chemical characteristics of the sediments in which these organisms live are influenced by currents, bathymetry, suspended particle load and other dynamic processes. Benthic habitats are therefore good indicators of environmental pertubations and have been extensively surveyed in this study in order to evaluate the effects of combined sewage overflows.

The sediment chemistry analysis program examined the physical and chemical characteristics of the surface sediments in areas potentially affected by the combined sewer overflows. This part of the field work was designed to determine: 1) whether these sediment characteristics change as a result of individual overflow events, and 2) whether there are any longer term cumulative affects that can be identified.

The benthic community assessment undertaken in this study provided information on the immediate impact of combined sewer overflow events and on the possible cumulative degradation of the benthic infauna during the study period. However, the benthic assessment did not provide control data to assess the benthic community changes which result from overflow events into an established and unperturbed benthic assemblage.

The locations for the 16 benthic and sediment stations were selected according to bathymetric contours and proximity to the wastewater overflow sites (Figure VI-1). Five benthic and sediment samplings were completed during this study and are summarized below:

Sampling Identification	Date	Comment
I	8 February 1979	pre-storm 1
II	23 February 1979	post-storm 1, pre-storm 2
III	5 March 1979	post-storm 2
IV	26 March 1979	pre-storm 3
V	2 April 1979	post-storm 3

Sampling II served as both the post-storm 1 and pre-storm 2 sampling because of the short period of time between the completion of storm 1 sampling and beginning of storm 2.

This period of time (12 days) would be insufficient to quantify opportunistic resettlement and recruitment of benthic infaunal organisms to the stations after possible perturbation by wastewater discharge.

During Sampling I and II, all 16 benthic stations were sampled. According to contract specifications, the number of stations were reduced to 10 for Sampling III. The selection of stations for continued sampling was based upon field observations and a preliminary survey of the sorted benthic infaunal organisms. Subsequent Samplings IV and V included 12 stations in accordance with contract specification changes.

The benthic infauna samples were obtained by using a 0.05 meter square Ponar grab sampler. Two replicate benthic samples were obtained at each station. Sediment core samples were also obtained from each of the benthic stations. The volume of each replicate was recorded and the samples were sealed in the bags and iced. Within hours the samples were washed through 1.0mm and 0.5mm sieves (aluminum frame, with Nitex mesh) and the separate fractions were transferred to pint specimen jars containing Rose Bengal (stain) and Clove Oil (10 drops/ml. narcotizing solution). Ten percent Formalin was added for fixation.

Replicate sediment samples were obtained using a Pfleger sediment corer, which takes a sample 30.5 cm long by 5.1 cm in diameter. The top 10 to 13 cm portion of the core was extruded for the sediment analyses. Sediment sample handling involved several techniques because of the different analyses performed. Replicate sediment samples used for trace metal analysis were obtained using a plastic liner and stainless steel fittings inside the Pfleger coring tube to prevent contamination. The trace metal sediment cores were extruded into plastic sample bags and iced. Sediment samples used for hydrocarbon analysis were obtained using the Pfleger aluminum core; the sediments were then extruded into glass jars with aluminum foil lined lids and frozen until analysis. Samples for sulfide analysis were extruded into plastic jars and mixed vigorously with 10 ml of 2N zinc acetate before being frozen.

The benthic infauna samples were kept in formalin for 24 to 48 hours, then rinsed with fresh water and preserved with 75 percent ethanol. The 1.0mm fraction were used in the data procurement, and the 0.5mm fractions are being curated in the eventuality that they may be useful in further resolving any changes found in the 1.0mm section or analysis of small organisms becomes warranted. The organisms in each replicate (1.0mm fraction) were then sorted into the major taxonomic groups, Vermes, Crustacea, Mollusca, Echinodermata, and Others. Using standard wet weight procedures (specimum equilibration in water, 5 minutes blotting on filter paper preceding weighing), the biomass for each major taxonomic group was determined using a Mettler H31AR Analytical Balance (Precision ±0.01 mg). The organisms from each replicate were identified to species (or the lowest taxon possible) and enumerated. The sediments were analyzed for cadmium, chromium, copper, lead, nickel, zinc, silver, arsenic, mercury, total organic carbon (T.O.C.), particle size distributions, oil and grease, percent hydrocarbons, total sulfide, and total identifiable chlorinated hydrocarbons (T.I.C.H.). The methods of analysis used were: T.O.C. and percent hydrocarbons (1); particle size analysis (2 and 3); T.I.C.H. (4, 5, 6); oil and grease, mercury, copper, cadmium, chromium, lead, nickel, zinc, and silver (5); total sulfide (6); and arsenic (7).

The numerical abundances of benthic infauna species are recorded for two replicates samples at each station (according to sampling period) as number of individuals per 0.05 meter square. The results from all stations and all sampling periods were analyzed for descriptive statistics. Biomass data for five major taxonomic groups is expressed for each replicate and as mean values for each station. The Shannon-Weiner Species Diversity Index was calculated for each replicate sample and mean values were determined for each station. The Shannon-Weiner index is computed as:

$$H^1 = - \sum_{i=1}^{s} p_i \log p_i$$

where p_i is the number of individuals of the i-th species divided by the total number of individuals in the sample. The numerical abundance data presented in Table G-1, Appendix G, was used for the calculation of the index. All species (including unidentified family spp.) were used in the index calculation. The index was calculated using base-e logarithms (natural logarithms).

RESULTS AND DISCUSSION - SEDIMENTS

The data for all sediment chemistry parameters collected at the 16 benthic stations during the five sampling periods are presented in Appendix F. Mean and standard deviation values for each sediment parameter analyzed are presented in Table VI-1.

Changes in the sediment chemistry attributable to C.S.O.'s were observed at several stations. The sediment metals content (Appendix F) shows that no detectable increase occurred throughout the study period or as a result of a single overflow event, except for lead increases at Station 12. The sediment lead increase at Station 12 (Islais Creek) is possibly a result of the C.S.O.'s point discharge of street run-off (a primary source of lead from auto emissions) (Ref. 8). Total organic carbon (T.O.C.) and the percent hydrocarbon (which represents the petroleum products contribution to oil and grease values) did not show any significant accumulation during the five sampling periods. Oil and grease values showed detectable increases only at Stations 1, 3 and 15 over the study period. No apparent relation was found between oil and grease quantities and the relative percentage of hydrocarbons. Total sulfide levels in the sediments showed an accumulative effect only at Stations 2, 7, 15 and 16 where the increases were moderate. Station 12 (end of Islais Creek) was the only site to show a large increase in the sediment concentration of Total Identifiable Chlorinated Hydrocarbons (T.I.C.H.), particularly P.C.B.'s (Arochlor).

Stations 1 through 8 are referred to as "Southern Stations." Stations 9 through 12 represent a transect through Islais Creek, from the mouth (Station 9) to within 100 yards of the combined sewer overflow (Station 12). Stations 13 through 16 represent the transect of Channel (Mission Creek) from the mouth (Station 13) to within 100 yards of the overflow (Station 16).

The particle size distribution data is presented as percentage greater than 62 microns (particles ranging from fine sands and coarser), percentage between 62 microns and 2 microns (silt fraction), and percentage below 2 microns (clay fraction). The fine sediments (silt-clay percentage, particles less than 62 microns) account for the majority of the particles in the benthic sediments at all stations except Station 8, where there was primarily shell fragments (Table VI-1 and Figure VI-2). Figure VI-2 depicts the changes in the silt and clay percentages of the sediments throughout the study area. The percentages of silt and clay at Stations 9 and 13 closely approximate the values for Stations 1 through 5, while Stations 6, 7 and 8 show the influence of the strong tidal currents around Hunters Point with coarser sediments. The reduced physical velocities and currents within Islais and Channel Creeks allow the settling of fine particles, which is indicated by the fine sediments at Stations 10, 11, 14 and 15 (Figure VI-2). The decrease in the silt-clay percentage values at Stations 12 and 16 is actually due to the large amounts of detrital particulate material at those stations (Ref. 11). The mean total organic carbon values reflect the changes in the fraction of silt-clay at each station (Table VI-1) and are related to differences in current velocities at the stations.

The variability in the particle size distributions from different samples taken at each benthic station is important to include when comparing changes in any of the sediment chemistry parameters at a station over time. Fine-grained sediments can have very high organic carbon contents since the large surface areas provided by these sediments increases the surface adsorption of particulate and sub-particulate materials (Ref. 9). Sub-particulates that are more readily adsorbed by fine sediments include silver, cadmium, copper, iron, lead, selenium, zinc, oil and grease, and chlorinated hydrocarbons (Refs. 8 and 10). Thus, much of the variability in the sediment chemistry parameters between sampling dates, at any station, can be accounted for by inspection of the particle size distribution data.

The accumulative impact of the C.S.O.'s on the benthic sediments is clearly evident and appears to be localized in the ends of Islais and Channel Creeks. The mean values for total sulfides, oil and grease, cadmium, mercury, lead, copper, zinc, silver, arsenic, nickel, and chromium which are presented in Table VI-1 are graphed in Figures VI-3 through VI-7. These figures illustrate that the sediment metal characteristics are influenced by the proximity of the stations to the discharge source as well as by the reduced tidal flushing within Islais and Channel Creeks.

For statistical analysis, stations were grouped according to their proximity to C.S.O. structures and a one-way analysis of variance was performed. The three groups of stations are identified as near (Stations 10, 11, 12, 14, 15, and 16), intermediate (Stations 5, 6, 7, 9, and 13), and far (Stations 1, 2, 3, 4, and 8). The results of the one-way analysis of variance for sediment chemistry data is presented in Table VI-2. Every sediment parameter tested proved to be significantly related to the proximity of the C.S.O.'s. An inspection of Figures VI-3 through VI-7 also shows that there is an inverse relation of mean parameter concentration (i.e., lead, zinc, cadmium, etc.) and distance from the discharge point for 10 of the 11 measured parameters in both Channel and Islais Creeks. Nickel is the only exception with the far stations having relatively high mean values.

These data were compared to recent historical sediment information (Refs. 8 and 12). The comparison shows that the data reported herein are within the range of historical data values. Measurements from in Channel and Islais Creeks are high but comparable to samples taken by the Port of San Francisco. Table VI-3 presents data within our study area, and the results are comparable.

RESULTS AND DISCUSSION - BENTHIC INFAUNA

A total of 132 benthic samples were collected and analyzed yielding a total of 37,869 individuals representing 139 species from 10 phyla (Table VI-4). The numerical abundance data per replicate and station; mean, median, and standard deviation, for species occurrence at each station for all sampling dates combined; and Shannon-Weiner species diversity index values for all stations and sampling dates are presented in Appendix G, Table G-1; and biomass data for five major taxonomic groups at each station are all presented in Table G-2, Appendix G.

Table VI-5 presents the total number of species and total number of individuals per replicate and station for each sampling period. The results do not indicate any definitive decrease in the number of species or individuals per station through the duration of the study or as a result of any single overflow event. The ability to ascertain trends is limited by the fact that only two replicates per station were collected and analysis was limited to the 1.0 mm fraction. The most abundant invertebrate species throughout all 16 stations are *Ampelisca milleri*, *Transennella tantilla*, *Sarsiella zostericola*, *Leptochelia dubia*, *Phoronopsis viridis*, and *Glycinde* sp.; which are predominantly representative of the stations distant from the C.S.O.'s immediate impact (Table VI-6). The ranked abundance list for benthic organisms in closest proximity to the C.S.O.'s (Islais and Channel Creeks) show only three of the most abundant species were common to both sloughs, and both regions had little overlap with the abundant species from stations away from the C.S.O.'s (Table VI-6). The five most abundant species found at Islais and Channel Creek stations are all either direct or indirect deposit feeders. In contrast, the five most abundant species present at those stations away from the C.S.O.'s (and not in regions of confined circulation such as Channel and Islais Creeks) are suspension feeders (*Ampelisca milleri*, *Leptochelia dubia*), filter feeders (*Transennella tantilla* and *Sarsiella zostericola*), and a ciliary-mucoid feeder (*Phoronopsis viridis*).

The mean total biomass values for each station are illustrated in Figures VI-8 through VI-12. For the southern stations, the molluscs, crustacea, and vermes were relatively even in biomass contributions for each station. For both Islais and Channel Creek stations, the mollusc fraction strongly predominate the total biomass values. The mean total biomass at each station consistently show the same relative biomass levels within each of the three regions of the study area (Figures VI-8 through VI-12).

Mean total biomass values for Channel Creek increased from zero at the head (Station 16) to moderate levels outside the mouth (Station 13). Mean total biomass values for Islais Creek follow the same basic pattern as Channel Creek. Stations 11 and 14, both within the creeks, have higher biomass values than stations outside--an indication of bivalve species utilizing the higher organics inside the creeks. There was no detectable short-term or cumulative effects to the benthic infaunal biomass due to C.S.O.'s.

The relative numbers of species and individuals did not show a significant change that was directly attributable to a single overflow event or three successive overflows (Figures VI-13 and VI-14). However, the numbers of species and individuals per station clearly illustrates the paucity of organisms in both Channel and Islais Creeks. Results of the benthic sediments analyses shows that the sediment near the terminus of each slough is an unsuitable environment for benthic organisms.

Station 16 (head of Channel Creek) had no animals present throughout the samplings, except one oligochaete from Sampling IV. Station 12 (head of Islais Creek) contained only 11 species, but six of those species were an unusual assortment. These six species collected at Station 12 consisted of one freshwater amphipod and five species of fly larvae. The fly larvae of particular interest were <u>Psychoda alternata</u> and <u>Psychoda severini</u>, commonly known as filter flys because they breed in sewage treatment plant trickling-filter beds, although CCSF does not have any trickling-filter plants. Apparently, the filter flys are using the C.S.O. conduits when inactive for depositing eggs, and the resultant larvae are washed out in subsequent overflows.

Species diversity values (a measure of the number of species and their relative abundances at a given site) in Figure VI-15 indicate that those stations considered intermediate and some classified as near (Stations 10, 11, 13, and 14) in their proximity to the C.S.O.'s have the highest species diversity of the entire study area. The increased species diversity and biomass apparently reflect the availability of food sources with increased organics in the sediments (T.O.C.; Table VI-1) and increased suspended organic materials from the C.S.O.'s. These results are similar to those of Filice (Ref. 13) with the exception of the increased diversity at intermediate distance to the outfall.

It is not possible to compare our results to previous studies except in the most rudimentary fashion for the following reasons: 1) variation in sampling methods among studies,

2) lack of previous studies which examine the area we studied, 3) possible mis-identification of species in previous studies, 4) lack of replicates in nearly all studies done to date, and 5) mis-use of diversity indices in comparing different studies. An excellent discussion of benthic surveys has been prepared by Nichols (Ref. 14).

SUMMARY

The sediment results indicate that the C.S.O.'s are significant point sources for the introduction of metals, oil and grease, and petroleum products (percent hydrocarbons), into the nearshore marine environment; and that there is a long-term cumulative effect localized near the points of discharge. The water movement and tidal currents flushing are important in reducing the concentration of the overflow discharge parameters that may accumulate in the sediments. This conclusion is supported by the observation that the values at the mouths of Islais and Channel Creeks are comparable to those unaffected by C.S.O.'s.

Benthic infauna results do not show any definitive decrease in biomass, number of species, or number of individual organisms through the duration of the study or as a result of any single overflow event. Numerically abundant benthic species from the stations in closest proximity to the C.S.O.'s (Islais and Channel Creeks) had only three species in common and both regions had minimal species overlap with the abundant species from stations away from the C.S.O.'s. Benthic stations in intermediate proximity to the C.S.O.'s had the highest species diversity and biomass, which reflects the increased availability of organic materials.

Literature Cited

1. American Public Health Association, "Standard Methods for the Examination of Water and Wastewater," 14th Ed, American Water Works Association, Water Pollution Control Federation, APHA, Washington, D.C. 1975.

2. American Society for Testing and Materials 1974. Part 19: D 422; Standard method for particle size analysis.

3. Folk, R.L. "Petrology of Sedimentary Rocks," 1974. Hemphill Publishing Co., Austin, Texas.

4. U.S. Environmental Protection Agency, "Analysis of Pesticide Residues in Human and Environmental Samples," 1974, Environmental Toxicology Division, Research Triangle Park, North Carolina.

5. U.S. Environmental Protection Agency, "Preliminary Sampling and Analytical Procedures for Evaluating the Disposal of Dredged Materials," 1974, Laboratory Support Branch, Region IX.

6. U.S. Environmental Protection Agency, "Chemistry Laboratory Manual for Bottom Sediments," 1969, Great Lakes Region Committee on Analytical Methods.

7. Martin, T.D. and J.E. Kopp, "Determining Selenium in Water, Wastewater, Sediment, and Sludge by Flameless Atomic Absorption Spectroscopy," 1975, Atomic Absorption Newsletter, Vol. 14, No. 5 Sept.

8. Riseborough, Robert W. et. al. 1978. Toxicants in San Francisco Bay and Estuary. Report to Assoc. Bay Area Governments. 113pp.

9. Newell, R.C. 1970. Biology of Intertidal Animals. American Elsevier Inc., New York. 555pp.

10. Disalvo, Louis H. 1978. Environmental Effects of Dredging and Disposal in the San Francisco Bay Estuarine System. Report to Assoc. Bay Area Governments. 51pp.

11. Personal observation of the benthic sediments during the five samplings.

12. Brown and Caldwell, Inc. 1975. A Predesign Report on Marine Waste Disposal. Vol. IV.

13. Filice, F.P. 1954. An ecological survey of the Castro Creek area in San Pablo Bay. Wassmann J. Biol. 12:1-24.

Filice, F.P. 1954. A study of some factors affecting the bottom fauna of a portion of the San Francisco estuary. Wassmann J. Biol. 12:257-292.

Filice, F.P. 1958. Invertebrates from the estuarine portion of San Francisco Bay and some factors influencing their distribution. Wassmann J. Biol. 16:159-211.

Filice, F.P. 1959. The effects of wastes on the distribution of bottom invertebrates in San Francisco Bay estuary. Wassmann J. Biol. 17:1-17.

14. Nichols, F.H. 1973. A review of benthic faunal surveys in San Francisco Bay. U.S. Dept. Int.; Geol. Survey Tech. Report 5 (Circ. 677). 20pp.

TAXONOMIC KEYS

Banse, Karl and Katharine D. Hobson 1974. Benthic Errantiate Polychaetes of British Columbia and Washington. Bulletin of the Fisheries Research Board of Canada; No. 185.

Barnard, J. L. 1954a. Amphipods of the Family Ampeliscidae collected in the eastern Pacific Ocean by the Velero III and Velero IV. Allan Hancock Pacific Expeditions Vol. 18(1):1-136. 38 plates.

Barnard, J. L. 1960. The amphipod family Phoxocephalidae in the eastern Pacific Ocean, with analysis of other species and notes for a revision of the family. Allan Hancock Pacific Expeditions. Vol. 18(3):175-369. 75 plates.

Barnard, J. L. 1962a. Benthic marine Amphipoda of southern California: Families Aoridae, Photidae, Ischyroceridae, Corophiidae, Podoceridae. Pac. Nat. 3:1-72.

Barnard, J. L. 1962b. Benthic marine Amphipoda of southern California: Families Tironidae to Gammaridae. Pac. Nat. 7:73-115.

Barnard, J. L. 1969b. The Families and Genera of Marine Gammaridean Amphipoda. U.S. Nat. Mus. Bull. 271:1-535.

Barnard, J. L. 1973. Revision of Corophiidae and Related Families (Amphipoda). Smith. Contr. Zool. 151:1-27.

Berkeley, E. and C. Berkeley. 1948. Canadian Pacific fauna 9. Annelida 9b(1) and 9b(2); Polychaeta Errantia (1-100) and Polychaeta Sedentaria (1-139). Fish. Res. Bd. Canada.

Coan, Eugene V. 1971. The Northwest American Tellinidae. Veliger. 11:1-50 (supp.).

Fauchald, K. 1977. The Polychaete Worms: definitions and keys to the orders, families and genera. Nat. Hist. Museum of L.A. County; Science Series 28.

Gladfelter, W. B. 1975. Quantitative distribution of shallow-water Cumacea from the vicinity of Dillon Beach, California, 29(3):242-250.

Hartman, Olga 1954. The marine annelids of San Francisco Bay and its environs, California. Allan Hancock Foundation Publ. Occ. Paper No. 15:1-20.

Hartman, Olga 1963. Submarine canyons of southern California, part III; systematics: polychaetes. Allan Hancock Pac. Exped. Vol. 27(3):1-93.

Hartman, Olga 1968. Atlas of the Errantiate Polychaetous Annelids from California. Allan Hancock Foundation Publ. 827 pp.

Hartman, Olga 1969. Atlas of the Sedentariate Polychaetous Annelids from California. Allan Hancock Foundation Publ. 809 pp.

Keen, A. Myra, and Eugene Coan 1974. Marine Molluscan Genera of Western North America: an illustrated key. Second Edition. Stanford University Press. 208 pp.

Kozloff, Eugene N. 1974. Keys to the Marine Invertebrates of Puget Sound, and San Juan Archipelago, and Adjacent Regions. University of Wash. Press. 226 pp.

Light's Manual: Intertidal Invertebrates of the Central California Coast. 1975. Ralph I. Smith and James T. Carlton, editors. Univ. of California Press, Berkeley.

Light, William. 1974. Occurrence of the Atlantic maldanid Asychis elongata (Maldanidae: Polychaeta) in San Francisco Bay. Proc. Biol. Society Wash. 87:175-184.

Oldroyd, I.S. 1924. Marine Shells of the West Coast of North America. Stanford Univ. Press. Volumes I & II.

Schmitt, W. L. 1921. The Marine Decapod Crustacea of California. Univ. Calif. Publication Zool. 23:470 pp.

Soot-Ryen, T. 1955. A report on the family Mytilidae (Pelecypoda). Univ. Southern Calif. Publ. (Allan Hancock Pacific Exp.) No. 20:1-175.

Swan, E.F. and J.H. Finucane. 1952. Observations on the genus Schizothaerus. Nautilus. 66:19-26.

Young, C. M. 1958. Observations on Petricola carditoides (Conrad). Proc. Malac. Soc., London. 33:25-31.

Table VI-1

Benthic Sediment Chemistry;
Means and Standard Deviations for 16 Benthic Stations

	STATION 1			STATION 2		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS						
mg/kg dry weight						
Cadmium	2	2.8	1.4	5	2.0	1.1
Chromium	2	140	14	5	149	36
Copper	2	50	6	5	42	14
Lead	2	39	2	5	36	10
Nickel	2	87	9	5	87	9
Zinc	2	120	14	5	117	16
Silver	2	0.8	0.7	5	0.9	0.6
Arsenic	2	4.9	1.1	5	5.1	1.9
Mercury	2	0.9	0.7	5	0.62	0.34
TOTAL ORGANIC CARBON						
% dry weight	2	1.37	0.01	5	1.33	0.07
OIL & GREASE						
mg/kg dry weight	2	13,790	18,690	5	2,170	2,790
HYDROCARBONS						
%	2	50	24	5	41	21
PARTICLE SIZE DISTRIBUTION						
% >62μ	2	18.3	13.1	5	16.6	4.3
% 2-62μ	2	47.7	5.7	5	48.7	3.4
% <2μ	2	34.2	7.6	5	34.8	4.8
TOTAL SULFIDE						
mg/kg wet weight	N/S	N/S	N/S	3	117	87
mg/kg dry weight	N/S	N/S	N/S	3	248	177
CHLORINATED HYDROCARBONS						
μg/kg dry weight						
AROCHLOR	2	10	11	5	4	4
DIELDRIN	2	<1	0	5	<1	0
PP'DDE	2	<1	0	5	<1	0
PP'DDD	2	<1	0	5	<1	0
PP'DDT	2	<1	0	5	0.6	0.3
OP DDT	2	<1	0	5	<1	0
OP DDD	2	<1	0	5	<1	0

Table VI-1
(Continued)

	STATION 3			STATION 4		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS mg/kg dry weight						
Cadmium	2	17.3	22.2	2	2.0	1.0
Chromium	2	143	18	2	158	11
Copper	2	53	4	2	60	1
Lead	2	43	16	2	45	2
Nickel	2	94	6	2	105	7
Zinc	2	123	18	2	141	1
Silver	2	0.6	0.4	2	<0.7	0
Arsenic	2	5.0	0.9	2	4.4	1.1
Mercury	2	1.2	1.3	2	0.9	0.5
TOTAL ORGANIC CARBON						
% dry weight	2	1.36	0.04	2	1.40	0.01
OIL & GREASE						
mg/kg dry weight	2	922	252	2	915	191
HYDROCARBONS						
%	2	36	18	2	61	33
PARTICLE SIZE DISTRIBUTION						
% >62μ	2	17.0	0.9	2	6.3	1.2
% 2-62μ	2	49.1	8.1	2	53.1	5.7
% <2μ	2	34.0	72	2	40.8	4.5
TOTAL SULFIDE						
mg/kg wet weight	N/S	N/S	N/S	N/S	N/S	N/S
mg/kg dry weight	N/S	N/S	N/S	N/S	N/S	N/S
CHLORINATED HYDROCARBONS μg/kg dry weight						
AROCHLOR	2	9	1	2	8	8
DIELDRIN	2	<1	0	2	<1	0
PP'DDE	2	<1	0	2	<1	0
PP'DDD	2	<1	0	2	<1	0
PP'DDT	2	<1	0	2	1.5	1.4
OP DDT	2	<1	0	2	<1	0
OP DDD	2	<1	0	2	<1	0

Table VI-1
(Continued)

	STATION 5			STATION 6		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS mg/kg dry weight						
Cadmium	5	1.6	0.3	5	1.3	0.3
Chromium	5	134	9	5	126	21
Copper	5	49	6	5	36	16
Lead	5	38	5	5	34	14
Nickel	5	85	9	5	82	11
Zinc	5	116	8	5	94	27
Silver	5	0.9	0.6	5	0.4	0.2
Arsenic	5	4.3	1.8	5	3.9	1.9
Mercury	5	0.43	0.10	5	0.3	0.1
TOTAL ORGANIC CARBON						
% dry weight	5	1.39	0.04	5	1.25	0.37
OIL & GREASE						
mg/kg dry weight	5	1,040	580	5	680	130
HYDROCARBONS						
%	5	46	23	5	40	23
PARTICLE SIZE DISTRIBUTION						
% >62μ	5	24.7	9.2	5	53.0	30.1
% 2-62μ	5	48.1	3.5	5	26.6	19.7
% <2μ	5	27.2	8.5	5	20.4	10.6
TOTAL SULFIDE						
mg/kg wet weight	3	219	225	3	657	990
mg/kg dry weight	3	461	456	3	1,017	1,459
CHLORINATED HYDROCARBONS μg/kg dry weight						
AROCHLOR	5	5	3	5	6	5
DIELDRIN	5	<1	0	5	<1	0
PP'DDE	5	<1	0	5	<1	0
PP'DDD	5	<1	0	5	<1	0
PP'DDT	5	1	1	5	<1	0
OP DDT	5	<1	0	5	<1	0
OP DDD	5	<1	0	5	<1	0

Table VI-1
(Continued)

	STATION 7			STATION 8		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS mg/kg dry weight						
Cadmium	5	1.9	0.4	2	2.4	1.6
Chromium	5	132	19	2	138	88
Copper	5	42	12	2	38	3
Lead	5	39	9	2	30	1
Nickel	5	87	9	2	113	81
Zinc	5	107	22	2	130	86
Silver	5	1.0	0.4	2	<0.7	0
Arsenic	5	3.8	1.4	2	2.6	1.8
Mercury	5	0.42	0.5	2	0.4	0.1
TOTAL ORGANIC CARBON						
% dry weight	5	1.32	0.31	2	0.33	0.21
OIL & GREASE						
mg/kg dry weight	5	850	460	2	155	35
HYDROCARBONS						
%	5	55	10	2	86	20
PARTICLE SIZE DISTRIBUTION						
% >62μ	5	37.5	25.0	2	93.5	1.3
% 2-62μ	5	33.0	16.8	2	2.7	1.7
% <2μ	5	29.5	8.2	2	3.9	0.4
TOTAL SULFIDE						
mg/kg wet weight	3	86	50	N/S	N/S	N/S
mg/kg dry weight	3	175	104	N/S	N/S	N/S
CHLORINATED HYDROCARBONS μg/kg dry weight						
AROCHLOR	5	5	6	2	7.3	6.7
DIELDRIN	5	<1	0	2	<1	0
PP'DDE	5	<1	0	2	<1	0
PP'DDD	5	0.9	1.0	2	<1	0
PP'DDT	5	1.2	1.2	2	<1	0
OP DDT	5	<1	0	2	<1	0
OP DDD	5	<1	0	2	<1	0

Table VI-1
(Continued)

	STATION 9			STATION 10		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS						
mg/kg dry weight						
Cadmium	5	1.4	0.4	4	2.4	0.5
Chromium	5	118	24	4	195	53
Copper	5	55	23	4	71	17
Lead	5	49	41	4	77	20
Nickel	5	89	15	4	126	45
Zinc	5	105	21	4	183	41
Silver	5	<0.7	0	4	1.0	0.4
Arsenic	5	4.2	0.5	4	6.1	1.1
Mercury	5	0.34	0.22	4	0.62	0.25
TOTAL ORGANIC CARBON						
% dry weight	5	1.21	0.22	4	1.78	0.05
OIL & GREASE						
mg/kg dry weight	5	912	484	4	2,348	1,114
HYDROCARBONS						
%	5	40	19	4	48	20
PARTICLE SIZE DISTRIBUTION						
% >62μ	5	26.9	14.9	4	3.9	1.4
% 2-62μ	5	44.8	8.7	4	51.2	13.1
% <2μ	5	28.3	10.6	4	45.0	11.9
TOTAL SULFIDE						
mg/kg wet weight	3	241	252	2	845	361
mg/kg dry weight	3	430	464	2	1,800	707
CHLORINATED HYDROCARBONS						
μg/kg dry weight						
AROCHLOR	5	11	10	4	7	4
DIELDRIN	5	<1	0	4	<1	0
PP'DDE	5	<1	0	4	<1	0
PP'DDD	5	<1	0	4	<1	0
PP'DDT	5	0.8	0.7	4	<1	0
OP DDT	5	<1	0	4	<1	0
OP DDD	5	<1	0	4	<1	0

Table VI-1
(Continued)

	STATION 11			STATION 12		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS mg/kg dry weight						
Cadmium	5	3.5	0.5	5	6.5	3.2
Chromium	5	234	21	5	534	225
Copper	5	83	27	5	184	82
Lead	5	131	12	5	882	482
Nickel	5	130	10	5	112	27
Zinc	5	279	63	5	984	241
Silver	5	1.8	0.5	5	9	3
Arsenic	5	6.3	1.6	4	6.4	2.3
Mercury	5	0.68	0.15	5	1.2	0.7
TOTAL ORGANIC CARBON						
% dry weight	5	2.21	0.25	5	6.48	0.63
OIL & GREASE						
mg/kg dry weight	5	4,000	1,017	5	26,300	4,147
HYDROCARBONS						
%	5	65	10	5	72	3
PARTICLE SIZE DISTRIBUTION						
% >62μ	5	2.8	1.0	5	32.4	14.7
% 2-62μ	5	48.7	4.9	5	30.8	10.0
% <2μ	5	48.5	4.5	5	36.8	14.3
TOTAL SULFIDE						
mg/kg wet weight	3	1,363	768	3	2,213	1,851
mg/kg dry weight	3	3,833	2,281	3	5,743	5,390
CHLORINATED HYDROCARBONS μg/kg dry weight						
AROCHLOR	5	12	9	5	500	713
DIELDRIN	5	0.7	0.5	5	5	7
PP'DDE	5	1.4	1.4	5	21	37
PP'DDD	5	0.9	0.9	5	5	6
PP'DDT	5	2.4	1.9	5	18	24
OP DDT	5	0.8	0.7	5	2	2
OP DDD	5	<1	0	5	1	2

Table VI-1
(Continued)

	STATION 13			STATION 14		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS						
mg/kg dry weight						
Cadmium	5	2.1	0.3	5	4.0	3.7
Chromium	5	145	7	5	161	23
Copper	5	61	8	5	73	9
Lead	5	48	3	5	103	55
Nickel	5	97	4	5	102	9
Zinc	5	137	8	5	192	72
Silver	5	0.9	0.5	5	1.2	0.5
Arsenic	5	4.6	0.17	5	5.0	1.5
Mercury	5	0.36	0.04	5	0.45	0.12
TOTAL ORGANIC CARBON						
% dry weight	5	1.54	0.09	5	1.82	0.04
OIL & GREASE						
mg/kg dry weight	5	1,485	444	5	2,040	483
HYDROCARBONS						
%	5	63	28	5	61	10
PARTICLE SIZE DISTRIBUTION						
% >62μ	5	12.7	3.4	5	3.1	1.2
% 2-62μ	5	50.8	3.2	5	51.1	9.5
% <2μ	5	36.5	4.8	5	45.8	9.2
TOTAL SULFIDE						
mg/kg wet weight	3	156	120	3	190	156
mg/kg dry weight	3	422	360	3	429	365
CHLORINATED HYDROCARBONS						
μg/kg dry weight						
AROCHLOR	5	5.5	4.1	5	4.2	3.8
DIELDRIN	5	<1	0	5	<1	0
PP'DDE	5	<1	0	5	<1	0
PP'DDD	5	<1	0	5	<1	0
PP'DDT	5	1.8	2.8	5	<1	0
OP DDT	5	<1	0	5	<1	0
OP DDD	5	<1	0	5	<1	0

Table VI-1
(Continued)

	STATION 15			STATION 16		
	n	$\bar{x}$	s	n	$\bar{x}$	s
METALS mg/kg dry weight						
Cadmium	4	5.0	1.0	5	8.6	0.7
Chromium	4	173	22	5	154	23
Copper	4	172	21	5	293	103
Lead	4	678	132	5	2,580	217
Nickel	4	113	14	5	94	5
Zinc	4	485	73	5	1,255	100
Silver	4	9.5	3.2	5	16	8
Arsenic	4	7.1	1.4	5	5.3	2.2
Mercury	4	2.0	0.8	5	2.5	1.2
TOTAL ORGANIC CARBON % dry weight	4	4.33	0.98	5	11.59	3.02
OIL & GREASE mg/kg dry weight	4	9,275	2,238	5	36,000	6,782
HYDROCARBONS %	4	75	3	5	68	2
PARTICLE SIZE DISTRIBUTION						
% >62μ	4	5.0	1.0	5	59.2	6.5
% 2-62μ	4	44.0	5.4	5	23.4	7.2
% <2μ	4	51.0	4.6	5	17.4	9.4
TOTAL SULFIDE						
mg/kg wet weight	2	934	1,225	3	1,478	1,312
mg/kg dry weight	2	2,285	2,991	3	3,333	2,804
CHLORINATED HYDROCARBONS μg/kg dry weight						
AROCHLOR	4	13	9	5	28.2	450
DIELDRIN	4	<1	0	5	<1	0
PP'DDE	4	1.3	1.6	5	2	4
PP'DDD	4	4	8	5	64	88
PP'DDT	4	11	14	5	73	105
OP DDT	4	<1	0	5	<1	0
OP DDD	4	<1	0	5	<1	0

Table VI-2

Sediment Chemistry Data: One-way Analysis of Variance to Compare Sediment Parameters to Proximity of C.S.O.'s

CADMIUM

Proximity	Sample Size	Mean	Standard Deviation
Near	28	5.1	2.8
Intermediate	25	1.6	0.4
Far	13	4.5	8.6

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.*
Between	169.081	2	84.54	4.771	0.0118
Within	1116.24	63	17.72		
Total	1285.32	65			

CHROMIUM

Proximity	Sample Size	Mean	Standard Deviation
Near	28	245.9	165.9
Intermediate	25	131.1	18.3
Far	13	146.2	34.1

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	195718.8	2	.9786E+05	8.051	0.0008
Within	765718.8	63	.1215E+05		
Total	961437.6	65			

*Significance level of probability, <.05.

Table VI-2
(Continued)

COPPER

Proximity	Sample Size	Mean	Standard Deviation
Near	28	147.8	98.4
Intermediate	25	48.8	15.9
Far	13	47.2	11.1

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	159586.1	2	.7979E+05	18.69	0.0000
Within	268916.3	63	4269		
Total	428502.4	65			

LEAD

Proximity	Sample Size	Mean	Standard Deviation
Near	28	767.8	939.9
Intermediate	25	41.8	19.2
Far	13	37.9	8.9

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	8527135	2	.4264E+10	11.26	0.0001
Within	0.2386038E+08	63	.3787E+06		
Total	0.3238751E+08	65			

Table VI-2
(Continued)

NICKEL

Proximity	Sample Size	Mean	Standard Deviation
Near	28	112.4	23.6
Intermediate	25	88.0	10.6
Far	13	94.9	26.2

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	8206.531	2	4103.	9.929	0.0002
Within	26036.56	63	413.3		
Total	34243.09	65			

ZINC

Proximity	Sample Size	Mean	Standard Deviation
Near	28	575.7	437.4
Intermediate	25	112.0	22.7
Far	13	124.2	28.4

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	3405936.	2	.1703E+07	20.68	0.0000
Within	5187980.	63	.8235E+05		
Total	8593915.	65			

Table VI-2
(Continued)

SILVER

Proximity	Sample Size	Mean	Standard Deviation
Near	28	7.293	7.6
Intermediate	25	.744	0.45
Far	13	.685	0.49

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	695.7255	2	347.9	14.03	0.000
Within	1561.902	63	24.79		
Total	2257.628	65			

ARSENIC

Proximity	Sample Size	Mean	Standard Deviation
Near	27	5.9	1.7
Intermediate	25	4.1	1.3
Far	13	4.5	1.6

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	45.89783	2	22.95	9.452	0.0003
Within	150.5376	62	2.428		
Total	196.4354	64			

Table VI-2
(Continued)

MERCURY

Proximity	Sample Size	Mean	Standard Deviation
Near	28	1.24	0.98
Intermediate	25	.37	0.24
Far	13	.75	0.56

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	10.06753	2	5.034	10.14	0.0002
Within	31.28925	63	.4967		
Total	41.35678	65			

TOTAL ORGANIC CARBON

Proximity	Sample Size	Mean	Standard Deviation
Near	28	4.8	3.86
Intermediate	25	1.3	0.25
Far	13	1.2	0.39

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	200.8240	2	100.4	15.63	0.0000
Within	404.8548	63	6.426		
Total	605.6787	65			

Table VI-2
(Continued)

OIL AND GREASE

Proximity	Sample Size	Mean	Standard Deviation
Near	28	13860	14010.8
Intermediate	25	993.4	491.5
Far	13	3262.	7355.1

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	0.2402184E+10	2	.1201E+10	12.71	0.0000
Within	0.5955149E+10	63	.9453E+08		
Total	0.8357332E+10	65			

PERCENT HYDROCARBONS

Proximity	Sample Size	Mean	Standard Deviation
Near	28	64.9	12.4
Intermediate	25	48.8	21.6
Far	13	51.5	25.5

Source	Sum of Sq.	D.F.	Mean Sq.	F	Prob.
Between	3811.625	2	1906.	5.179	0.0083
Within	23184.19	63	368.0		
Total	26995.82	65			

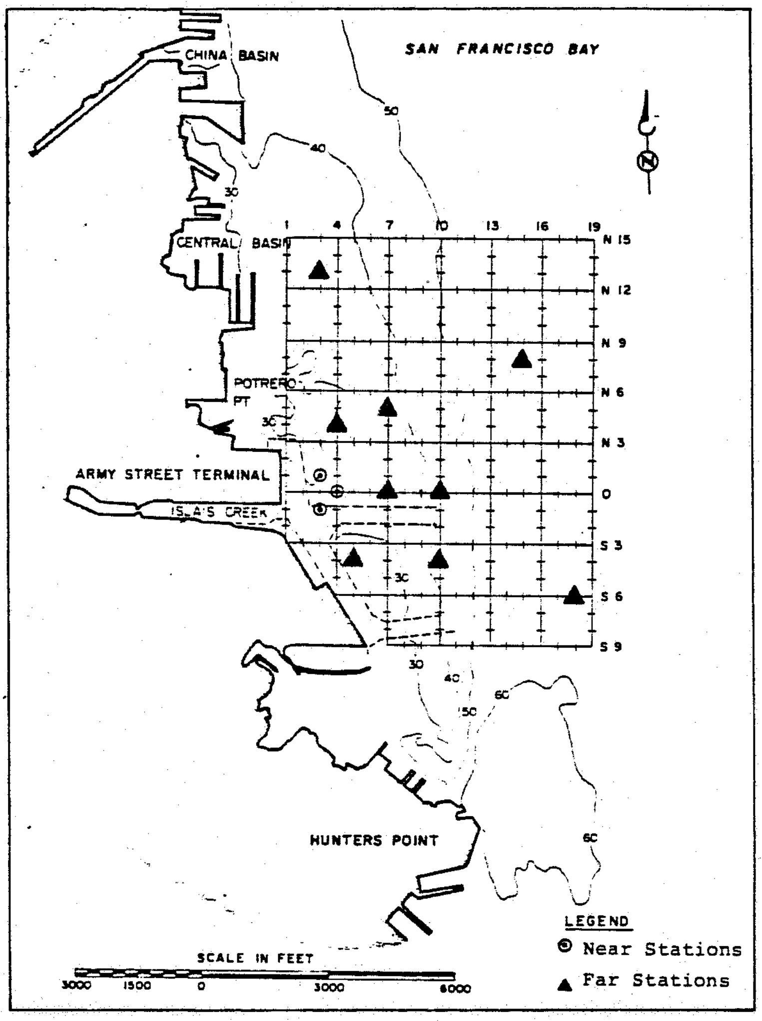
Table VI-3

Heavy Metals in Sediments Near Islais Creek
and in Other Areas of San Francisco Bay (from Brown and Caldwell, 1975)
(mg/kg dry weight)

		Cd	Cu	Cr	Hg	Ni	Pb	Zn
Near*	Mean	1.047	42.3	112.3	1.240	75.0	44.3	112.7
	Standard Deviation	.071	11.2	14.7	.793	58.8	3.2	25.9
Far**	Mean	1.399	43.0	114.1	.796	100.9	55.0	122.2
	Standard Deviation	.286	11.4	13.2	.889	11.6	19.8	36.4

*Stations 0-4, NI-3, SI-3

**Stations N5-7, N8-15, N13-3, S4-10, S6-18, N4-4, 0-7, 0-10, S4-5



Map of Study Area Showing Sediment Sampling Stations in the Vicinity of the Southeast WPCP Outfall, South San Francisco Bay

TABLE VI - 4

BENTHIC INVERTEBRATES
SPECIES LIST

Phylum Cnidaria
  Class Hydrozoa
    unidentified spp.
  Class Anthozoa
    unidentified spp.

Phylum Nemertea
    unidentified spp.

Phylum Annelida
  Class Oligochaeta
    unidentified spp.

  Class Polychaeta
    Family Polynoidae
      Harmothoe priops Hartman, 1961
      Harmothoe spp.

    Family Sigalionidae
      Pholoe minuta (Fabricius, 1780)

    Family Phyllodocidae
      Anaitides sp
      Eteone lighti Hartman, 1936
      Eteone pacifica Hartman, 1936
      Exogone gracilis
      Exogone lourei
      Exogone sp.
      unidentified spp.

    Family Hesionidae
      Gyptis brevipalpa (Hartmann-Schroeder, 1959)

    Family Nereidae
      Nereis pelagica neonigripes Hartman, 1936

    Family Nephtyidae
      Nephtys caecoides Hartman, 1938
      Nephtys cornuta franciscana Clark and Jones, 1955
      Nephtys sp.

    Family Glyceridae
      Glycera americana Leidy, 1955
      Hemipodus borealis Johnson, 1901

TABLE VI - 4
(Continued)

Family Goniadidae
  Glycinde sp.

Family Lumbrineridae
  Lumbrineris sp.

Family Dorvilleidae
  Schistomeringos cf. rudolphi (delle Chiaje, 1828)
  unidentified spp.

Family Orbiniidae
  Leitoscoloplos pugettensis (Johnson, 1901)

Family Spionidae
  Polydora brachycephala Hartman, 1936
  Polydora lighti Webster, 1879
  Polydora sp.
  *Pseudopolydora kempi (Southern, 1921)
  Spiophanes bombyx (Claparède, 1870)
  Spiophanes berkeleyorum Pettibone, 1962
  Streblospio benedicti Webster, 1879
  unidentified spp.

Family cirratulida
  Cirratulus cirratus (Müller, 1776)
  Cirratulus sp.
  Cirriformia spirabrancha (Moore, 1904)
  Tharyx cf. monilaris
  unidentified spp.

Family Cossuridae
  Cossura pygodactylata Jones, 1956

Family Opheliidae
  Armandia brevis (Moore, 1906)
  Ophelia limacina (Rathke, 1842)

Family Capitellidae
  Capitella capitata (Fabricius, 1780)
  Heteromastus filiformis (Claparede, 1864
  Heteromastus sp.
  Notomastus tenuis Moore, 1909
  Notomastus sp.
  unidentified spp.

Family Oweniidae
  Owenia collaris Hartman, 1955

TABLE VI - 4
(Continued)

Family Maldanidae
*Asychis elongata (Verrill, 1873)
unidentified spp.

Family Pectinariidae
Pectinaria californiensis Hartman, 1941

Family Ampharetidae
unidentified spp.

Family Terebellidae
Amaeana occidentalis (Hartman, 1944)

Family Sabellidae
Chone gracilis Moore, 1906
Chone sp.

Phylum Mollusca
Class Gastropoda
Subclass Prosobranchia
Order Mesogastropoda
Crepidula convexa Say, 1822
Crepidula plana Say, 1822
Crepidula sp.
Order Neogastropoda
Mitrella aurantiaca (Dall, 1871)

Subclass Opisthobranchia
Order Cephalaspidea
Aglaja sp.
Philine sp. (juv.)
Rictaxis punctocaelatus (Carpenter, 1874)

Class Pelecypoda
Family Nuculanidae
Nuculana sp. (juv.)
Yoldia sp. (juv.)

Family Mytilidae
Adula sp. (juv.)
*Musculus senhousia (Benson, 1842)
Mytilus edulis Linnaeus, 1758

Family Ostreidae
Ostrea lurida Carpenter 1864

Family Lucinidae
unidentified spp.

TABLE VI - 4
(Continued)

Family Montacutidae
Mysella sp.

Family Cardiidae
Clinocardium nuttallii (Conrad, 1837)

Family Veneridae
Protothaca staminea (Conrad, 1837)
Saxidomus nuttalli Conrad, 1837
**Tapes japonica* Deshayes, 1853
Transennella tantilla (Gould, 1853)

Family Petricolidae
Petricola carditoides (Conrad, 1837)

Family Cooperellidae
Cooperella subdiaphana (Carpenter, 1864)

Family Mactridae
Tresus nuttallii (Conrad, 1837)

Family Tellinidae
Macoma balthica (Linneaus, 1758)
Macoma nasuta (Conrad, 1837)
Macoma spp. (juv.)
Tellina spp. (juv.)

Family Solenidae
Siliqua lurida (Conrad, 1837)
Siliqua sp. (juv.)
Solen sicarius Gould, 1850

Family Myidae
Cryptomya californica (Conrad, 1837)
Sphenia fragilis

Family Pholadidae
Zirfaea pilsbryi Lowe, 1931

Family Lyonsiidae
Lyonsia californica Conrad, 1837

Phylum Arthropoda
Class Crustacea
Subclass Ostracoda
**Sarsiella zostericola*

TABLE VI - 4
(Continued)

Subclass Cirripedia
  Balanus crenatus Bruguiere, 1789

Subclass Malacostraca
  Order Cumacea
    Lamprops quadriplicata Smith, 1879
    Eudorella pacifica Hart, 1930

  Order Tanaidacea
    Leptochelia dubia (Kroyer, 1842)

  Order Isopoda
    "*Dynamenella*" *sheareri* Hatch, 1947
    Sphaeroma pentodon Richardson, 1904
    Jaeropsis dubia dubia Menzies, 1951

  Order Amphipoda
    Suborder Gammaridea
    Ampelisca milleri Barnard, 1954
    Amphithoe plumulosa Shoemaker, 1938
    Amphithoe valida Smith, 1873
    **Corophium acheriusicum* Costa, 1857
    **Corophium insidiosum* Crawford, 1937
    **Corophium uenoi* Stephensen, 1932
    Corophium spp.
    **Grandidierella japonica* Stephensen, 1938
    Microdeutopus schmitti Shoemaker, 1942
    Photis brevipes Shoemaker, 1942
    Paraphoxus obtusidens (Alderman, 1936)
    unidentified spp.
    Crangonyx sp.
   Suborder Caprellidea
    Caprella californica Stimpson, 1857

Order Decapoda
  Suborder Natantia
    Heptacarpus cristatus (Stimpson, 1860)
    Crangon nigricauda Stimpson, 1856
    Crangon nigromaculata Lockington, 1877
    unidentified spp.

  Suborder Reptantia
    Section Brachyura
      Cancer gracilis Dana, 1852
      Cancer sp.
      Hemigrapsus oregonensis (Dana 1851)
      Pinnixa franciscana Rathbun, 1981
      unidentified Pinnotheridae (juv.)
      Pyromaia tuberculata Lockington, 1877)
      unidentified megalops
      unidentified spp. (juv.)

TABLE VI - 4
(Continued)

Class Insecta
Order Diptera
Hydropholus sp.
Ploisotoma laguna
Psychoda alternata
Psychoda severini
unidentified spp. (puparium)

Class Psychogonida
unidentified spp.

Phylum Sipunculida
unidentified sp.

Phylum Ectoplocta
unidentified spp.

Phylum Phoronida
Phoronopsis viridis Hilton, 1930
unidientified sp.

Phylum Echinodermata
Class Ophiuroidea
Amphipholus squamata (Delle Chiaje, 1829)
Class Holothuroidea
unidentified spp.

Phylum Chordata
Molgula sp.
unidentified Gobiidae
unidentified Pleuronectidae (juv.)
unidentified fish larvae

*Denotes introduced species

Table VI-5

Number of Individuals and Number of Species
Per Station, According to Sampling Period

PERIOD I

	Replicate 1		Replicate 2			
Station	Total Species	Total Number of Animals	Total Species	Total Number of Animals	Total Species	Mean Number of Animals
1	10	329	11	375	15	352
2	11	729	13	292	17	511
3	12	322	10	406	14	362
4	13	313	9	143	14	228
5	7	391	10	398	12	395
6	14	121	17	259	23	190
7	13	130	20	262	25	196
8	14	101	15	180	19	141
9	16	260	19	998	28	629
10	4	13	3	4	6	8.5
11	6	24	11	35	11	29.5
12	0	0	1	1	1	.5
13	5	20	5	15	7	17.5
14	11	27	3	5	11	7.0
15	2	4	0	0	2	2.0
16	0	0	0	0	0	0

Table VI-5
(Continued)

PERIOD II

Station	Replicate 1		Replicate 2			
	Total Species	Total Number of Animals	Total Species	Total Number of Animals	Total Species	Mean Number of Animals
1	10	296	10	210	14	253
2	12	307	10	304	15	306
3	12	436	9	222	12	329
4	16	418	15	428	21	423
5	15	411	13	670	19	541
6	18	594	16	1,335	23	965
7	20	104	26	1,295	33	700
8	6	37	6	52	10	45
9	17	1,110	23	714	25	912
10	4	13	4	12	7	12.5
11	8	27	9	71	12	49
12	6	34	5	25	9	29.5
13	12	39	16	56	19	47.5
14	11	64	5	28	13	46
15	2	15	1	4	2	9.5
16	0	0	0	0	0	0

Table VI-5
(Continued)

PERIOD III

Station	Replicate 1 Total Species	Replicate 1 Total Number of Animals	Replicate 2 Total Species	Replicate 2 Total Number of Animals	Total Species	Mean Number of Animals
1	N/S	N/S	N/S	N/S	N/S	N/S
2	9	309	12	362	15	335.5
3	N/S	N/S	N/S	N/S	N/S	N/S
4	N/S	N/S	N/S	N/S	N/S	N/S
5	17	528	18	407	23	467.5
6	13	1,038	12	466	14	752
7	14	199	12	122	19	160.5
8	N/S	N/S	N/S	N/S	N/S	N/S
9	27	1,437	21	1,763	31	1,600
10	N/S	N/S	N/S	N/S	N/S	N/S
11	12	138	10	116	13	127
12	1	1	0	0	1	0.5
13	3	15	18	65	18	40
14	16	32	13	38	19	35
15	N/S	N/S	N/S	N/S	N/S	N/S
16	0	0	0	0	0	0

Table VI-5
(Continued)

PERIOD IV

	Replicate 1		Replicate 2			
Station	Total Species	Total Number of Animals	Total Species	Total Number of Animals	Total Species	Mean Number of Animals
1	N/S	N/S	N/S	N/S	N/S	N/S
2	12	202	9	154	15	178
3	N/S	N/S	N/S	N/S	N/S	N/S
4	N/S	N/S	N/S	N/S	N/S	N/S
5	14	312	21	346	27	329
6	16	213	13	405	22	309
7	23	1,207	25	1,214	31	1,210.5
8	N/S	N/S	N/S	N/S	N/S	N/S
9	32	1,696	36	1,925	47	1,810.5
10	10	18	11	32	14	40
11	6	30	8	81	9	55.5
12	3	4	2	2	4	3
13	16	35	6	9	19	11
14	16	81	13	45	18	63
15	3	3	2	2	5	2.5
16	1	1	0	0	1	0.5

Table VI-5
(Continued)

PERIOD V

Station	Replicate 1		Replicate 2			
	Total Species	Total Number of Animals	Total Species	Total Number of Animals	Total Species	Mean Number of Animals
1	N/S	N/S	N/S	N/S	N/S	N/S
2	17	209	18	263	22	236
3	N/S	N/S	N/S	N/S	N/S	N/S
4	N/S	N/S	N/S	N/S	N/S	N/S
5	23	324	18	283	27	304
6	24	783	16	365	27	574
7	29	1,201	27	1,052	25	1,127
8	N/S	N/S	N/S	N/S	N/S	N/S
9	24	617	38	1,861	40	1,239
10	12	31	5	27	13	29
11	16	59	13	113	21	86
12	2	3	0	0	2	1.5
13	9	22	11	34	13	28
14	15	33	16	41	25	37.0
15	5	6	1	1	5	3.5
16	0	0	0	0	0	0

Table IV-6

Ranked abundance of 10 most abundant benthic invertebrate species at stations away from the overflow (1, 2, 3, 4, 5, 6, 7, 8, 9, 13).

Species	$\bar{X}/.05m^2$
Ampelisca milleri	316.48
Transennella tantilla	27.16
Sarsiella zostericola	20.09
Leptochelia dubia	11.18
Phoronopsis viridis	6.63
Glycinde sp.	6.59
Tapes japonica	5.30
Leitoscoloplos pugettensis	4.69
Grandidierella japonica	4.66
Asychis elongata	2.30

Ranked abundance of the 10 most abundant benthic invertebrate species at Stations 14, 15 and 16 (Channel Creek).

Species	$\bar{X}/.05m^2$
Macoma spp. (juv.)	2.81
Oligochaeta	1.99
Macoma nasuta	1.53
Tharyx cf. *monilaris*	1.40
Glycinde sp.	1.09
unidentified Cirratulidae	0.77
Leitoscoloplos pugettensis	0.66
Nephtys cornuta franciscana	0.47
Heteromastus filibranchus	0.47
Tharyx sp.	0.33

Ranked abundance of the 10 most abundant benthic invertebrate species at Stations 10, 11, and 12 (Islais Creek).

Species	$\bar{X}/.05m^2$
Capitella capitata	7.86
Macoma nasuta	3.24
Oligochaeta	3.21
Cirratulus cirratus	3.20
Cirriformia spirabranchia	2.83
Ampelisca milleri	1.60
Psychoda alternata	1.43
Transennella tantilla	1.40
Streblospio benedicti	1.28
Glycinde sp.	0.79

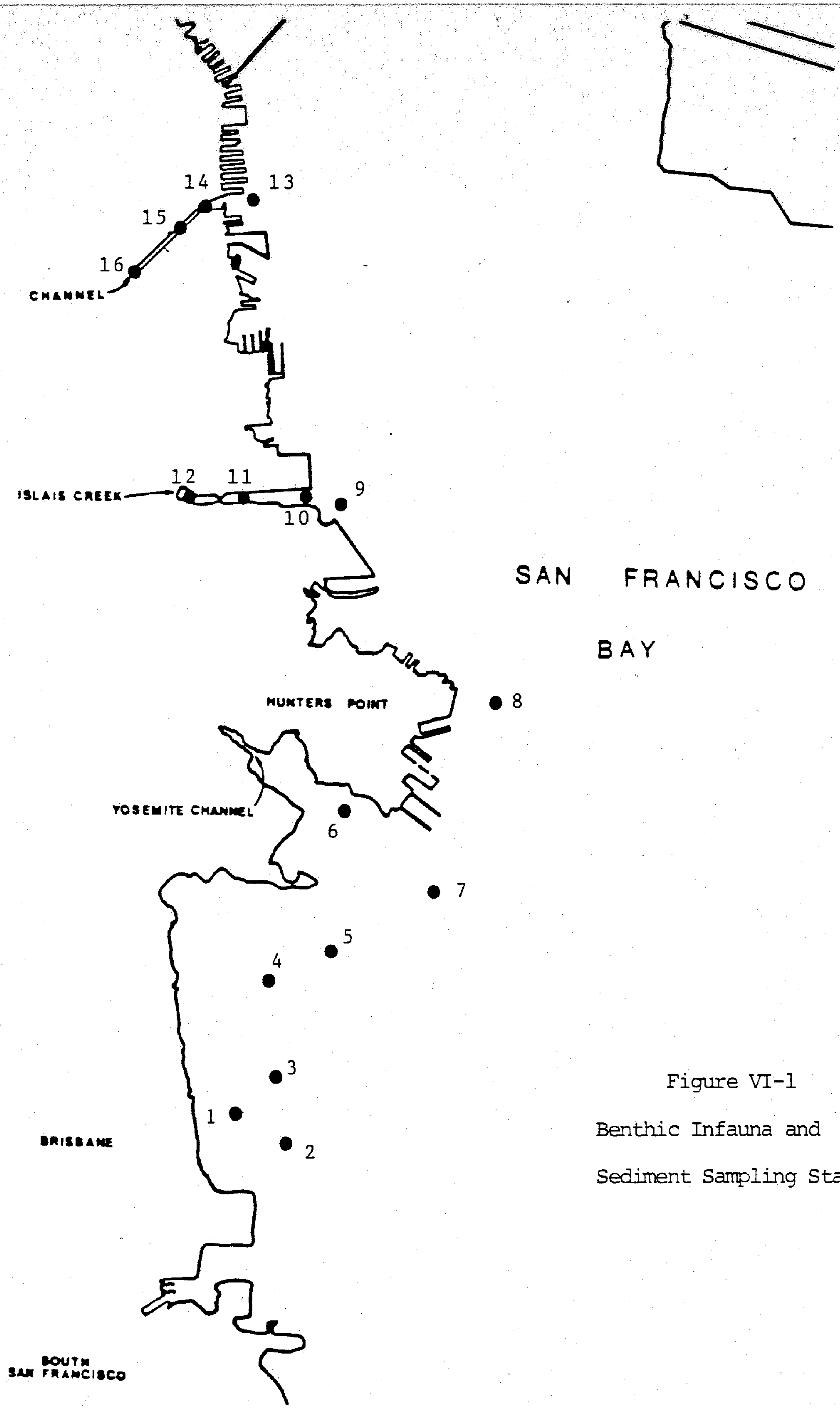


Figure VI-1

Benthic Infauna and

Sediment Sampling Stations.

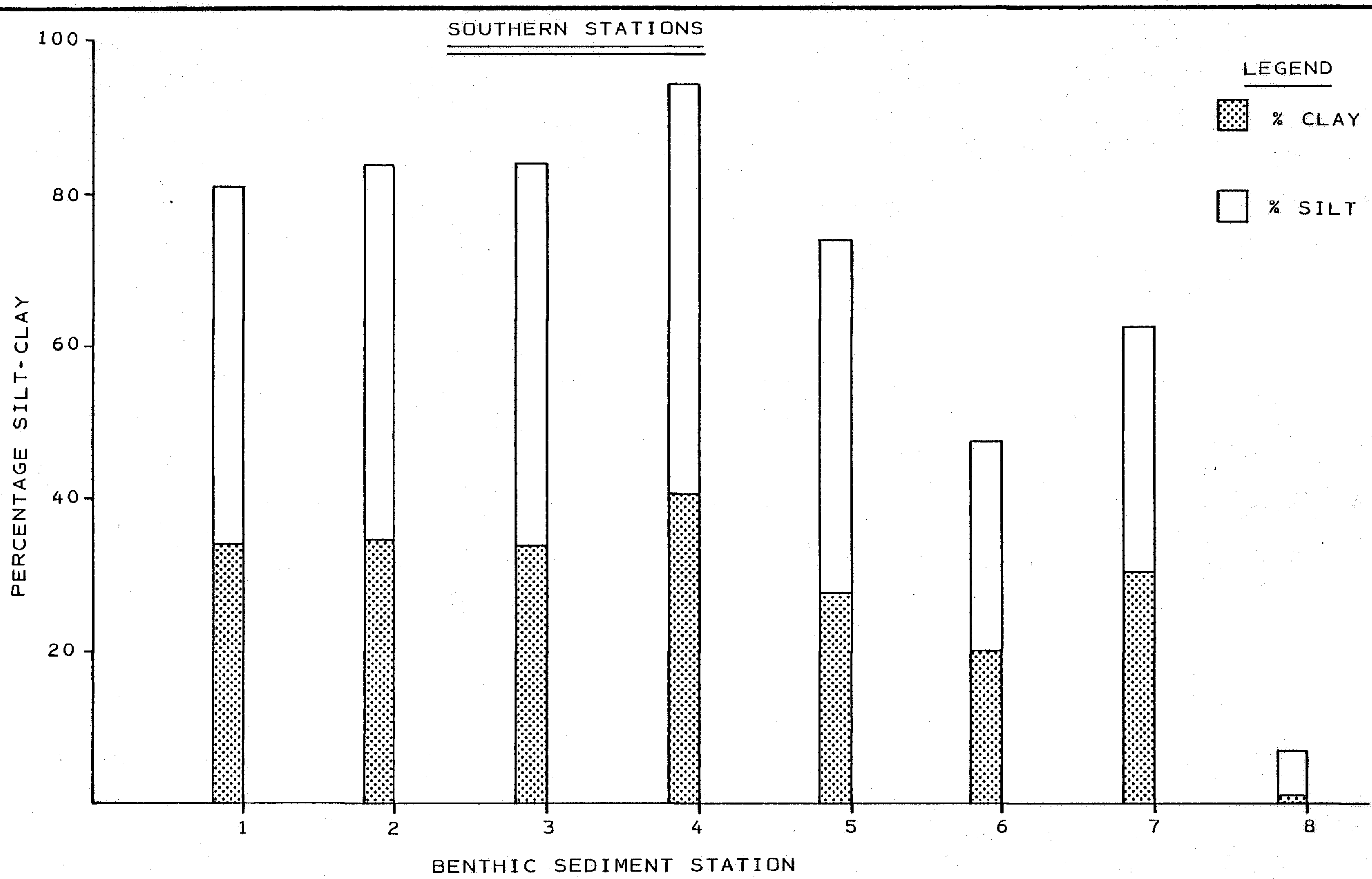


FIGURE VI-2
BENTHIC SEDIMENTS PARTICLE SIZE
DISTRIBUTION (MEAN VALUES)

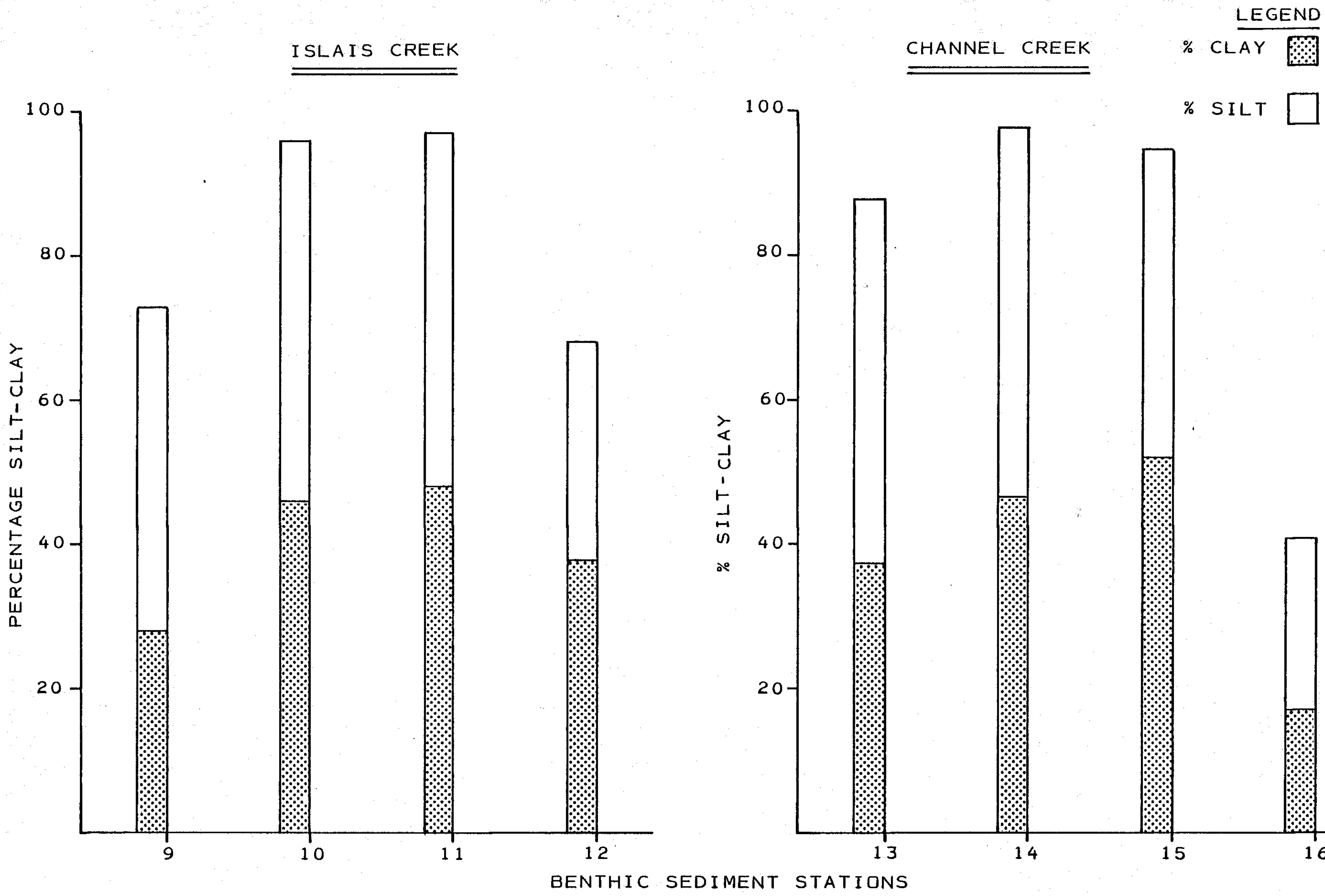


FIGURE VI-2 (CONT.)

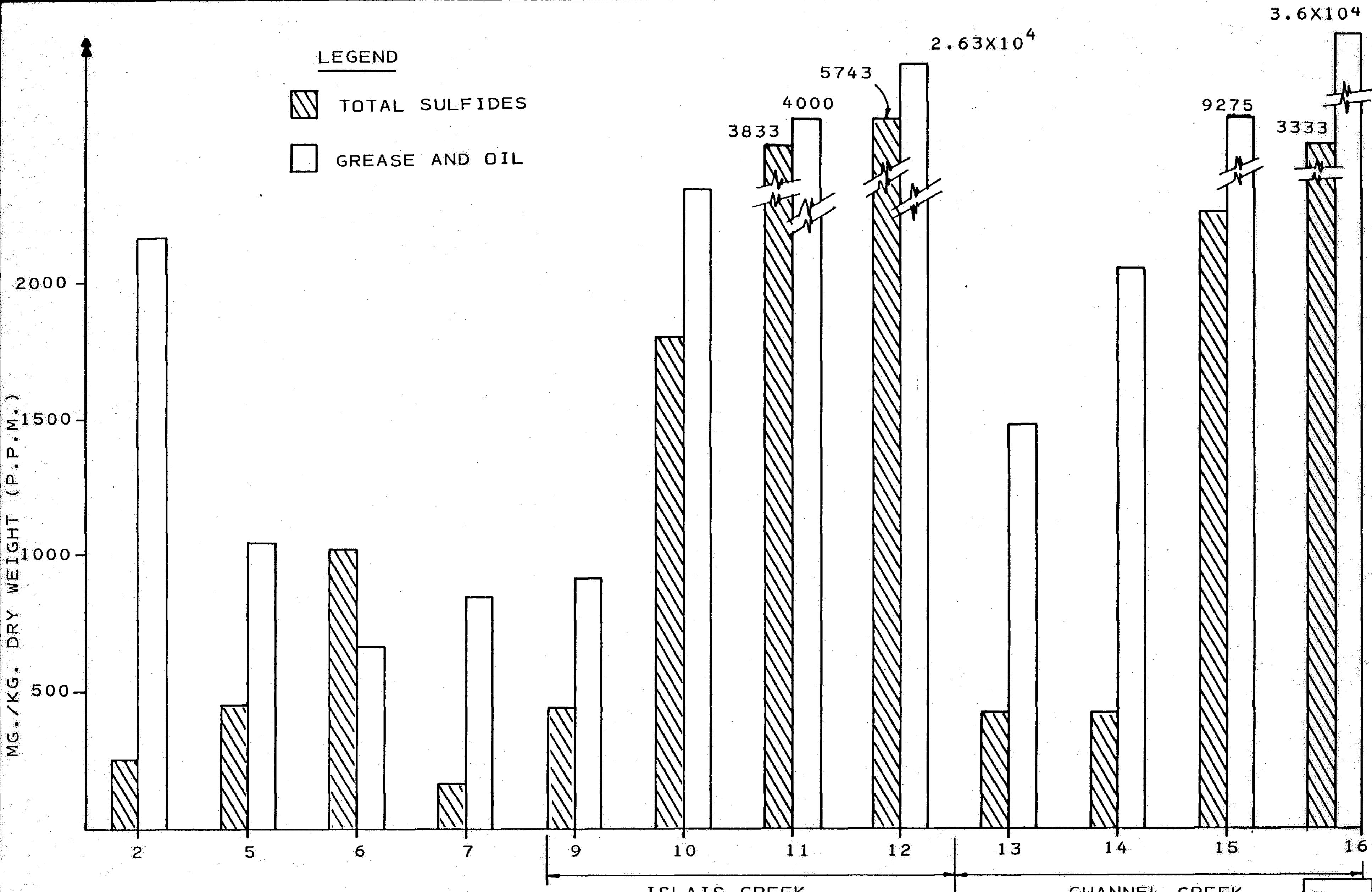


FIGURE VI-3
BENTHIC SEDIMENTS TOTAL SULFIDES
AND GREASE AND OIL (MEAN VALUES)

CH2M HILL

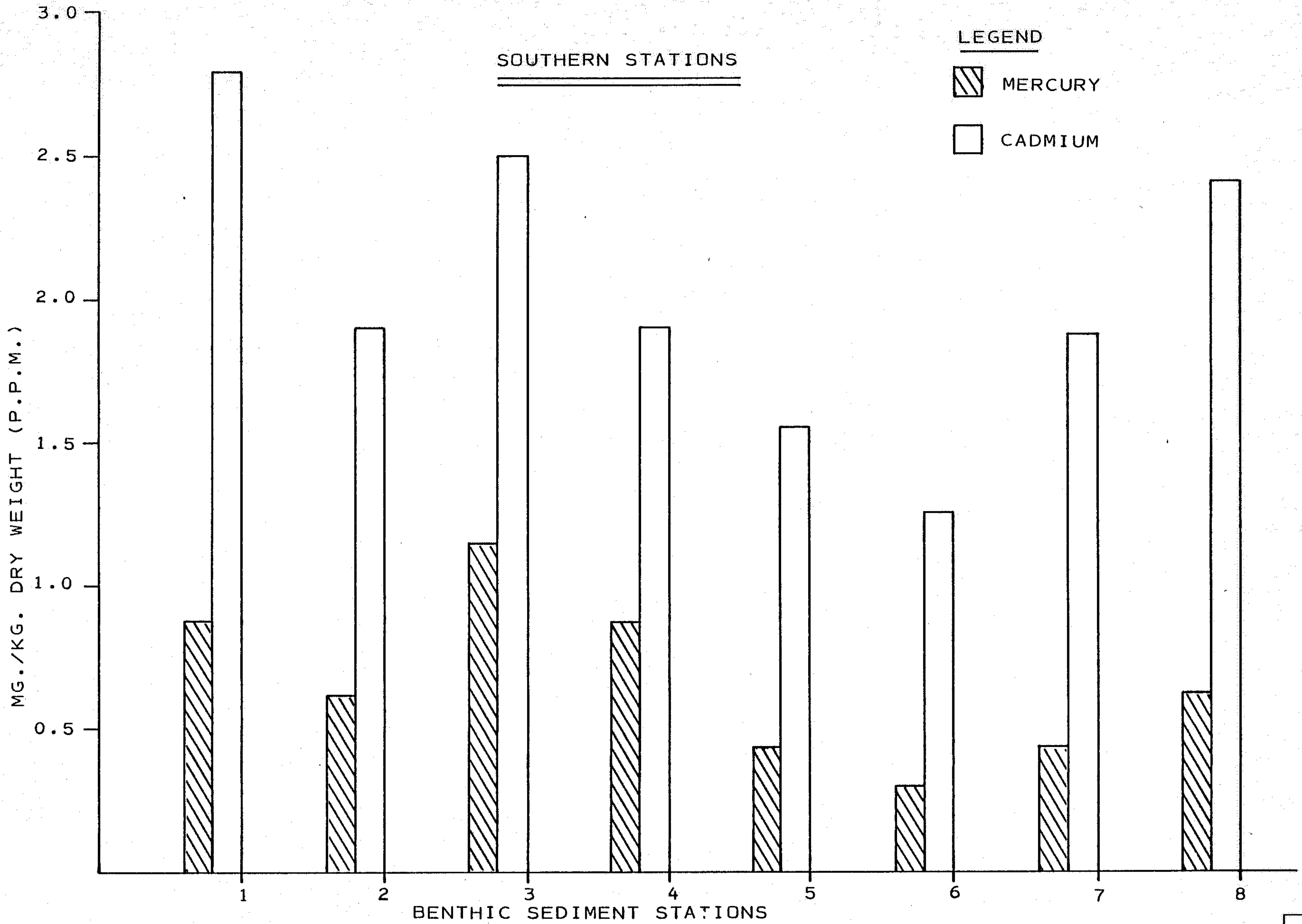


FIGURE VI-4
MEAN CADMIUM AND MERCURY
CONCENTRATIONS IN BENTHIC SEDIMENTS

CH2M HILL

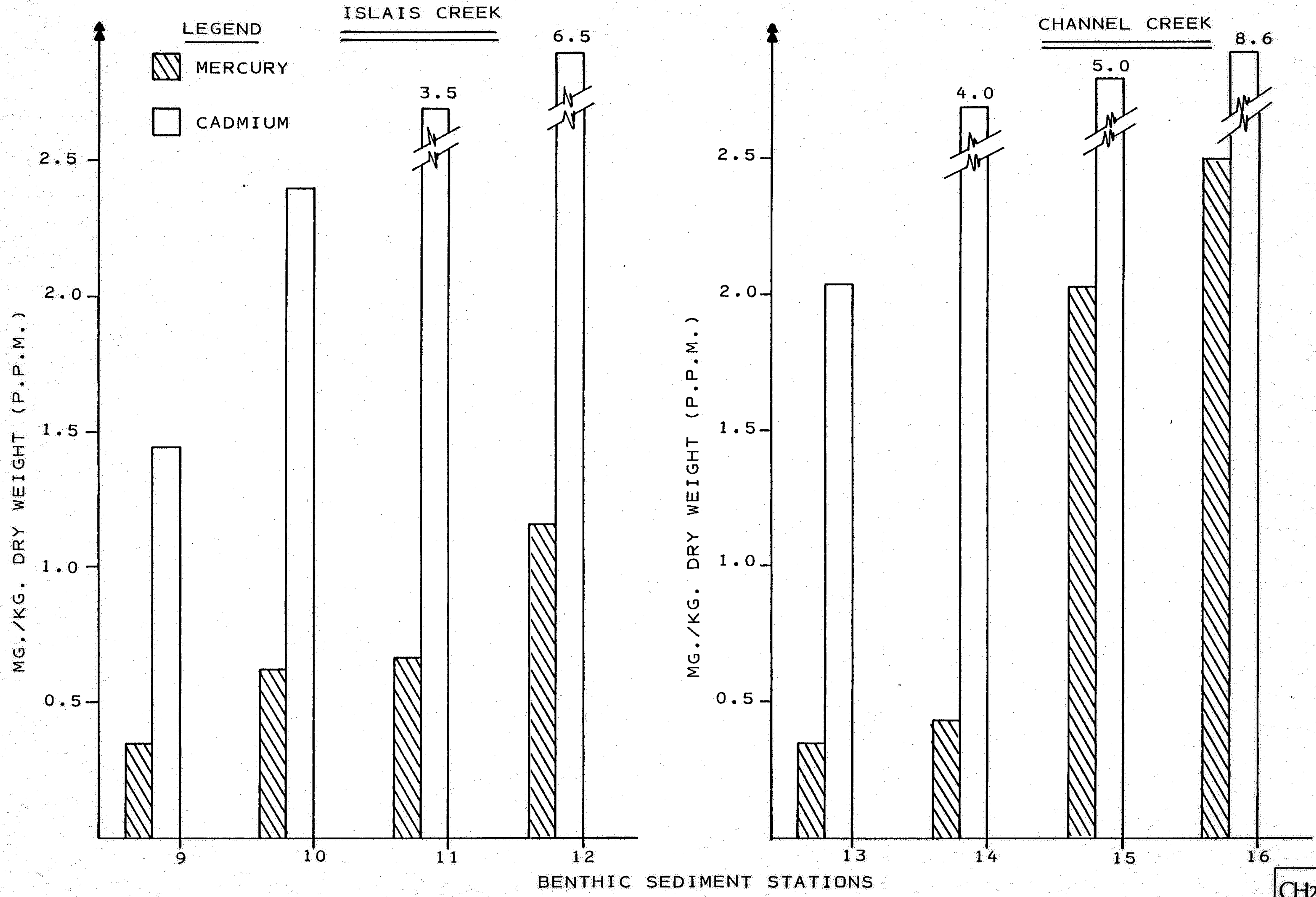


FIGURE VI-4 (CONT.)

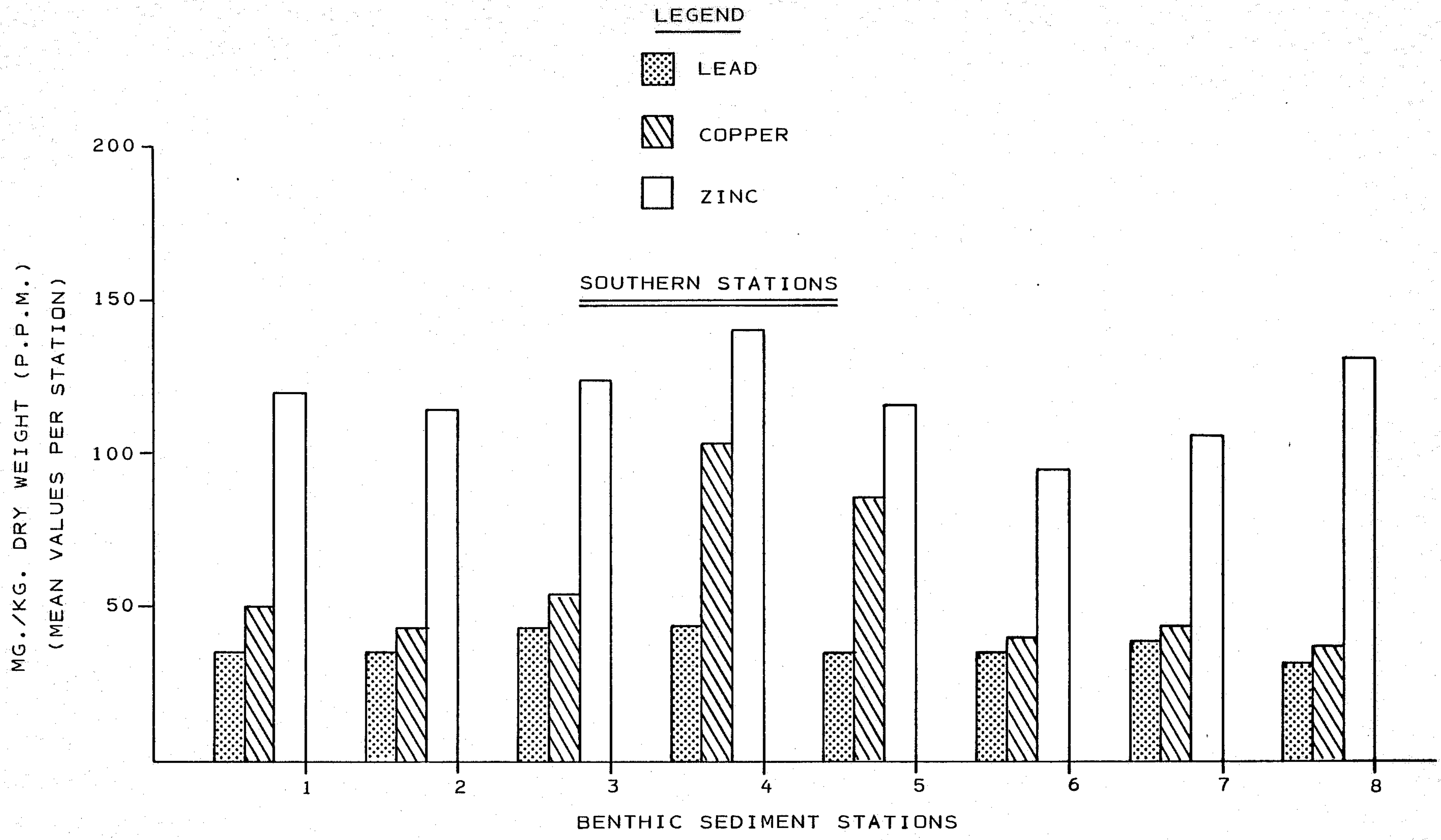


FIGURE VI-5
MEAN LEAD, COPPER, AND ZINC
CONCENTRATONS IN BENTHIC SEDIMENTS

CH2M HILL

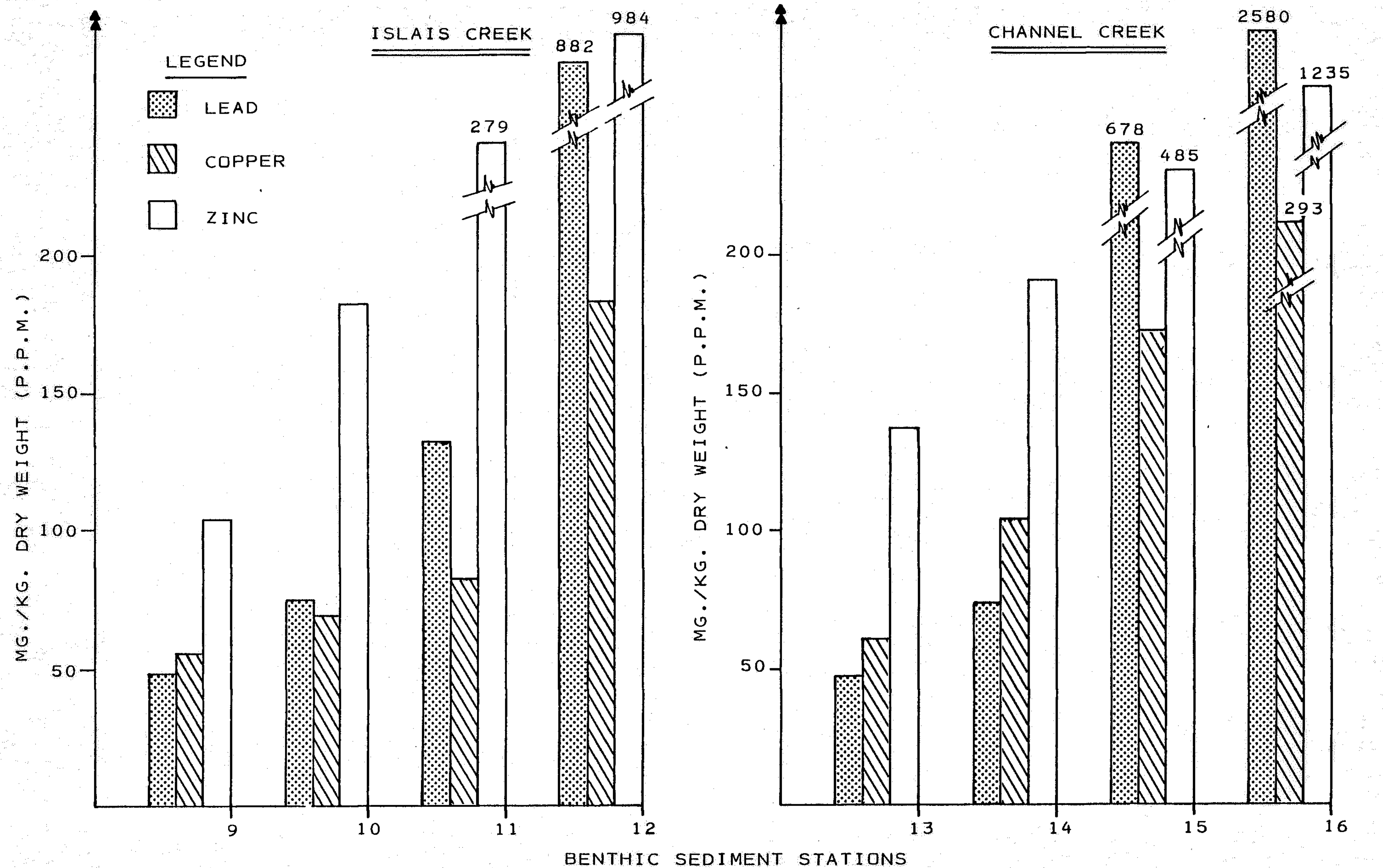


FIGURE VI-5 (CONT.)

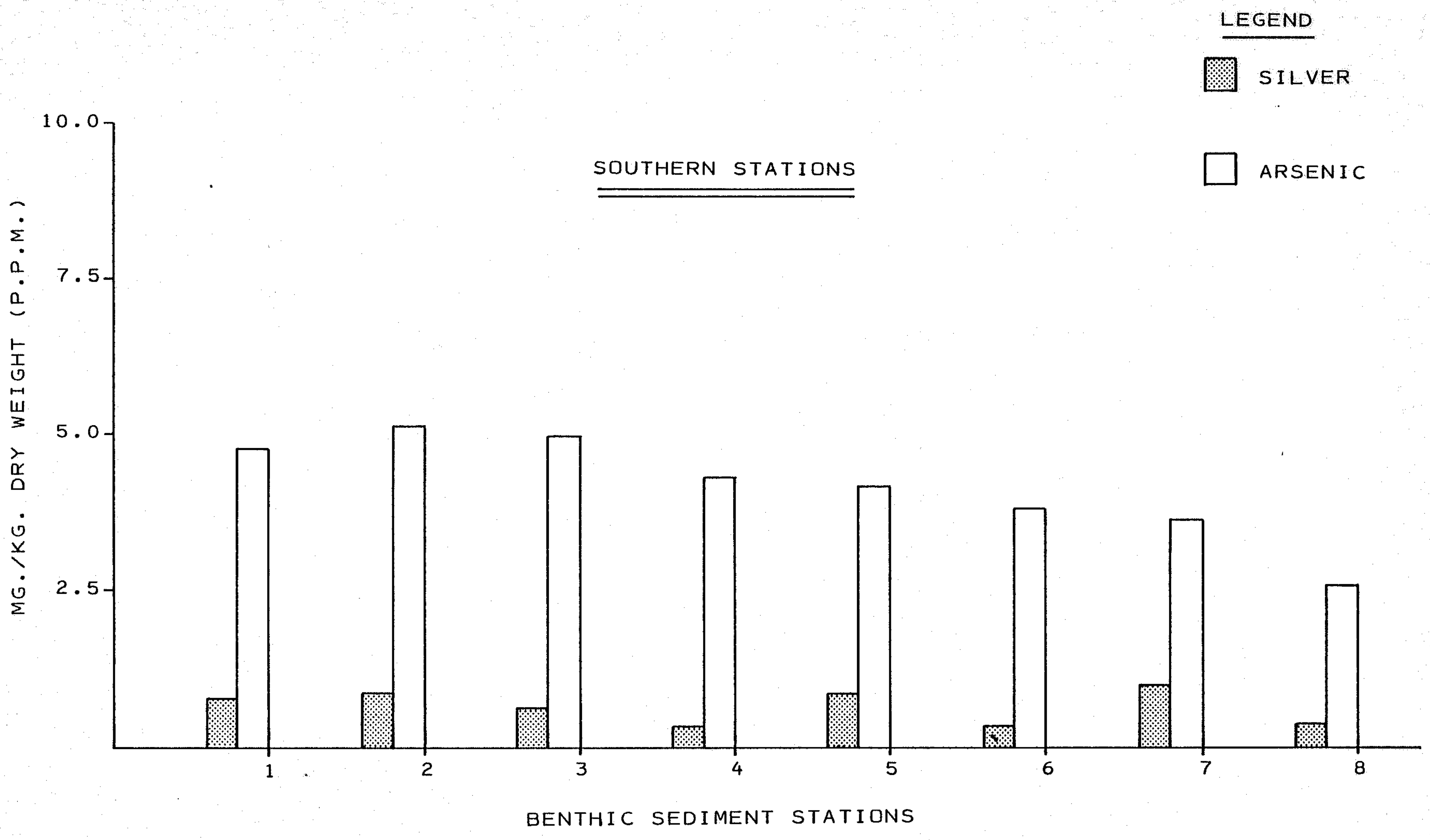


FIGURE VI-6
MEAN SILVER AND ARSENIC
CONCENTRATIONS IN BENTHIC SEDIMENTS

CH2M HILL

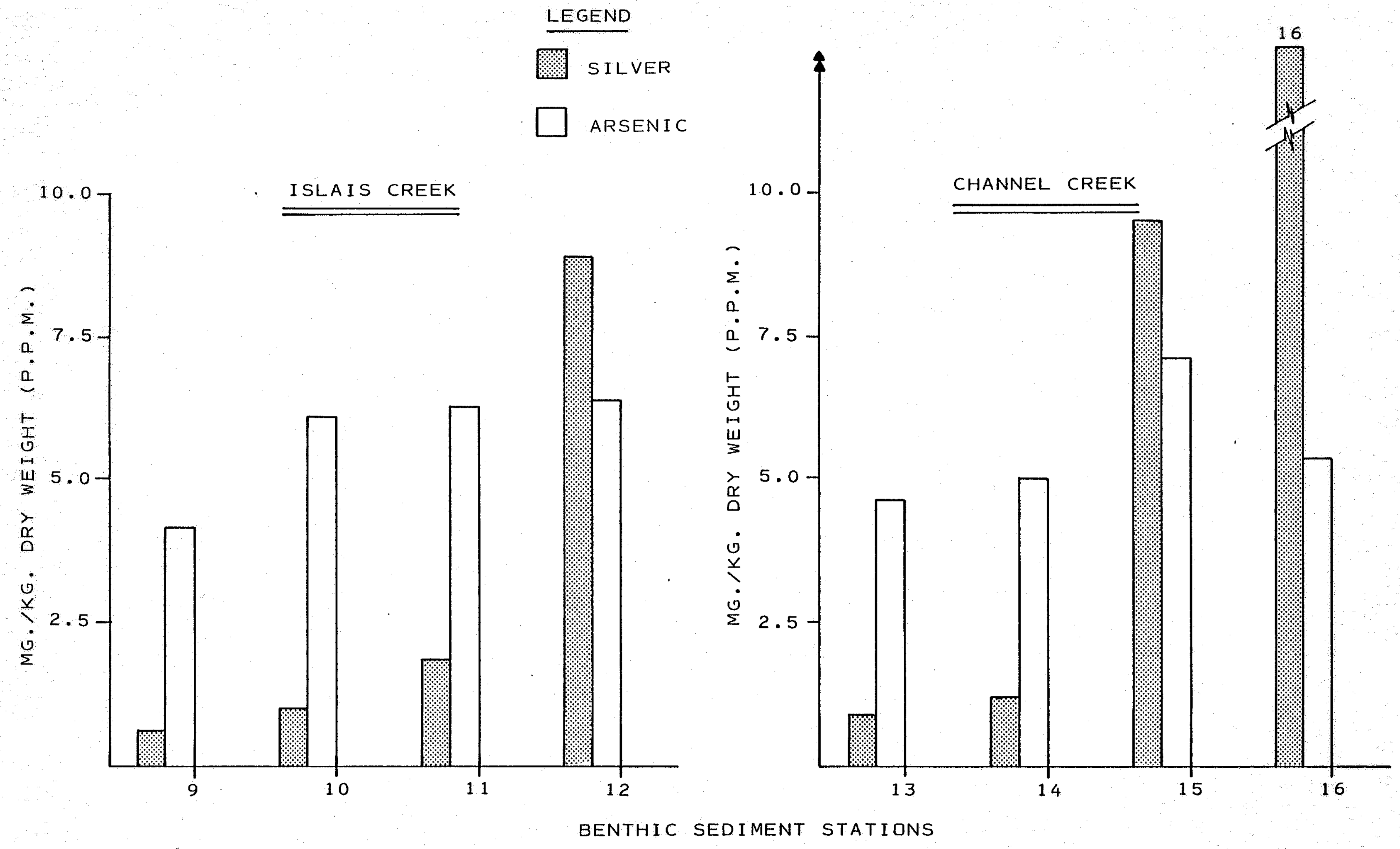


FIGURE VI-6 (CONT.)

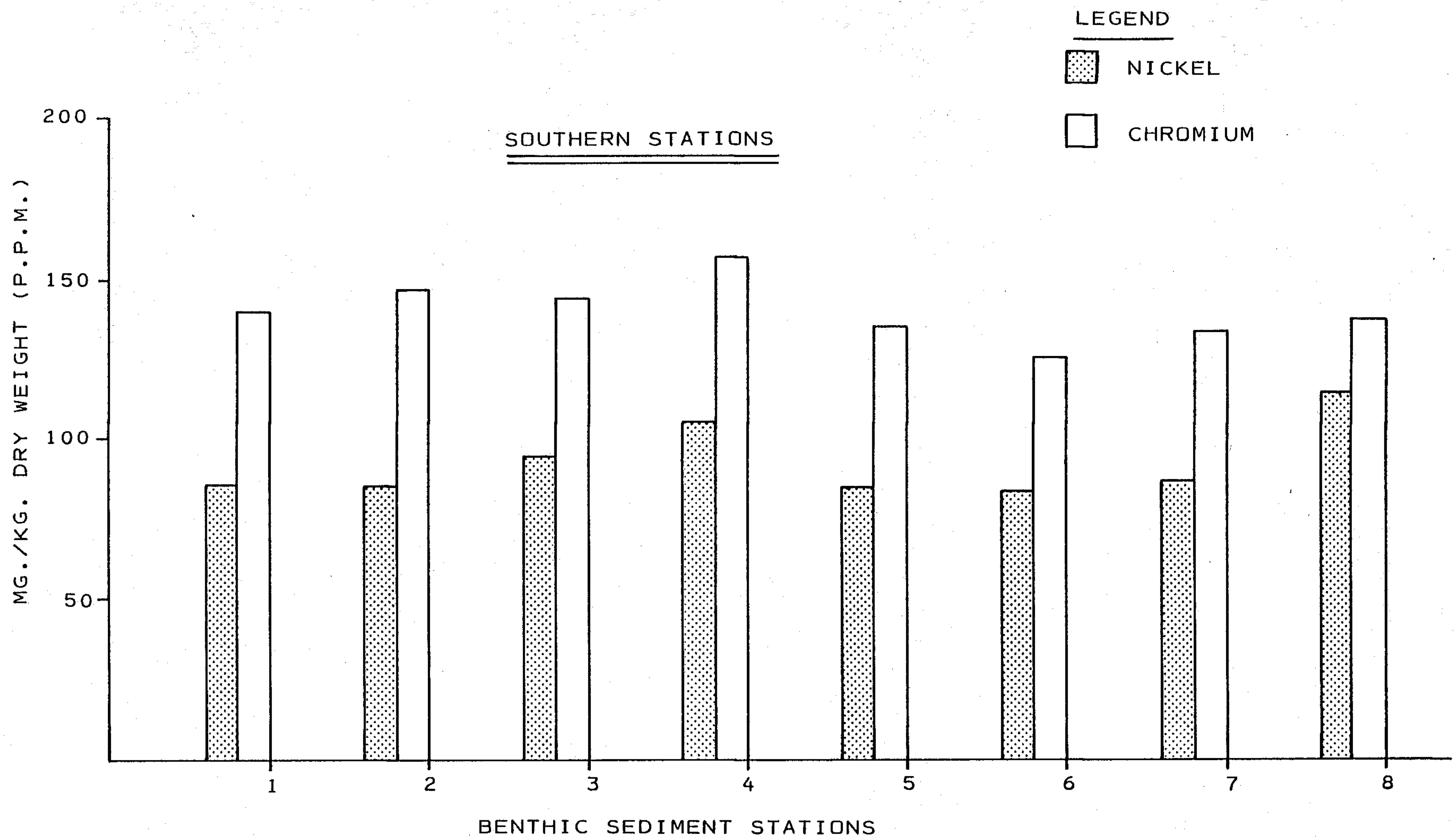


FIGURE VI-7
MEAN CHROMIUM AND NICKEL
CONCENTRATIONS IN BENTHIC SEDIMENTS

CH2M HILL

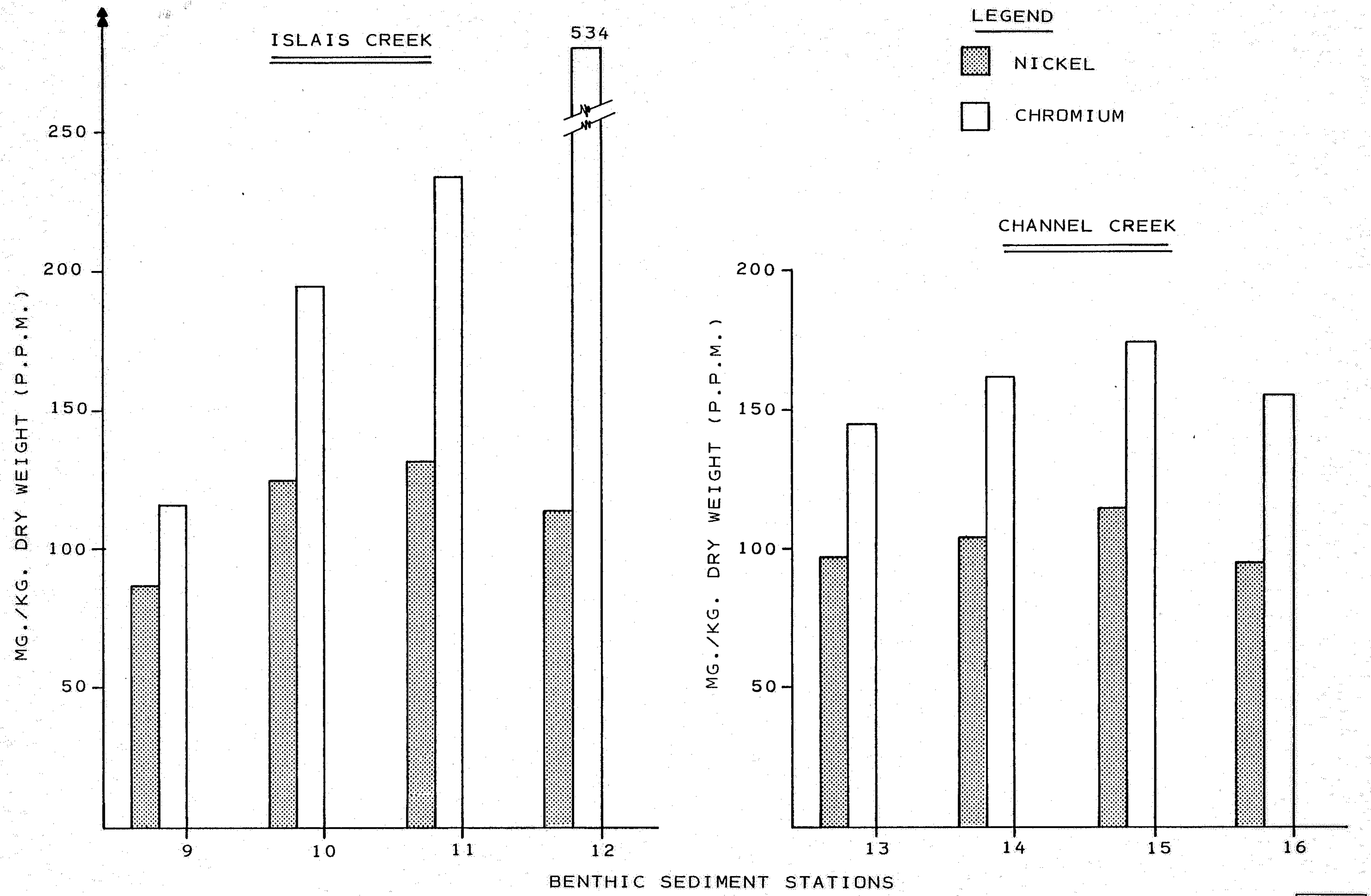


FIGURE VI-7 (CONT.)

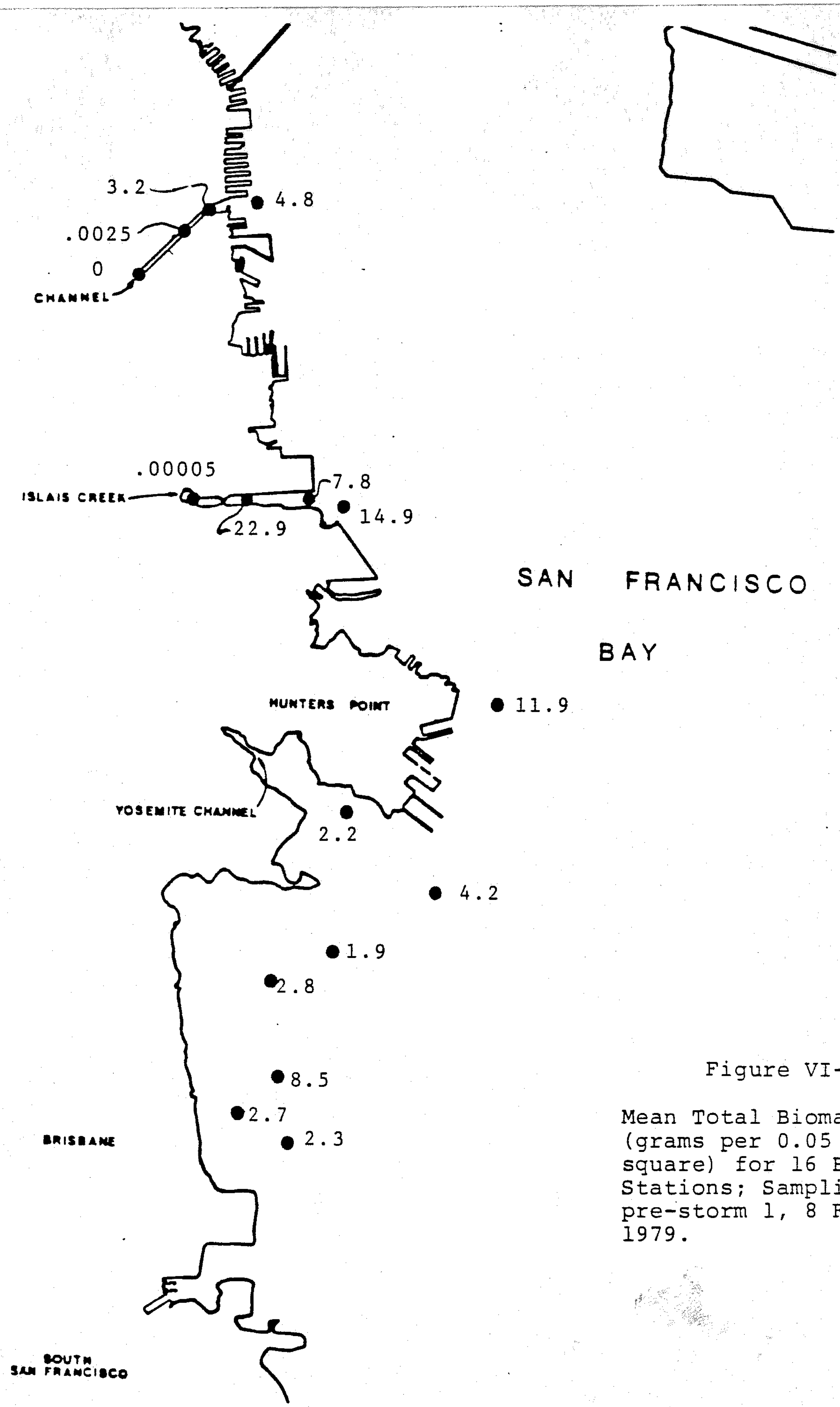


Figure VI-8

Mean Total Biomass (grams per 0.05 meter square) for 16 Benthic Stations; Sampling I, pre-storm 1, 8 February 1979.

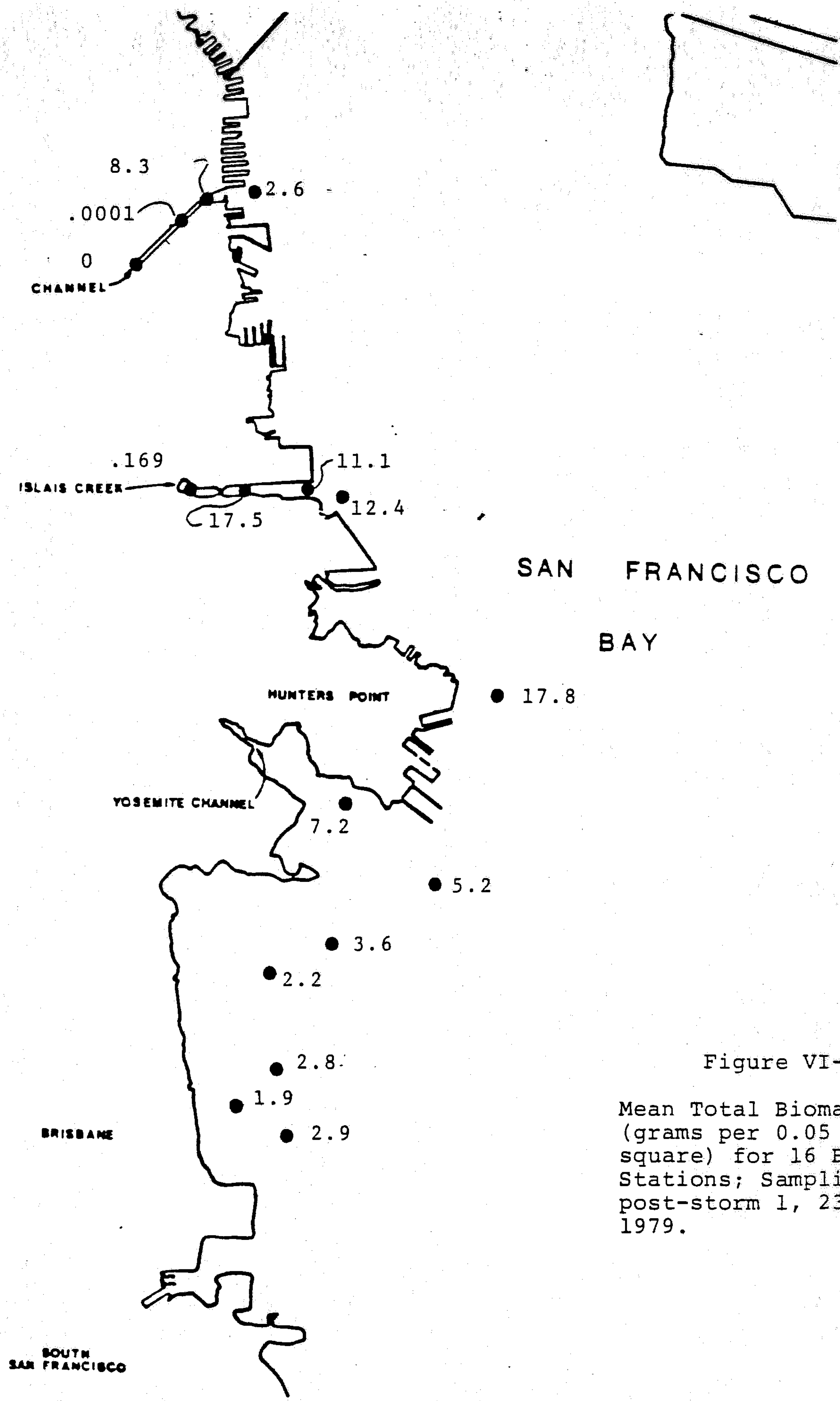


Figure VI-9

Mean Total Biomass (grams per 0.05 meter square) for 16 Benthic Stations; Sampling II, post-storm 1, 23 February 1979.

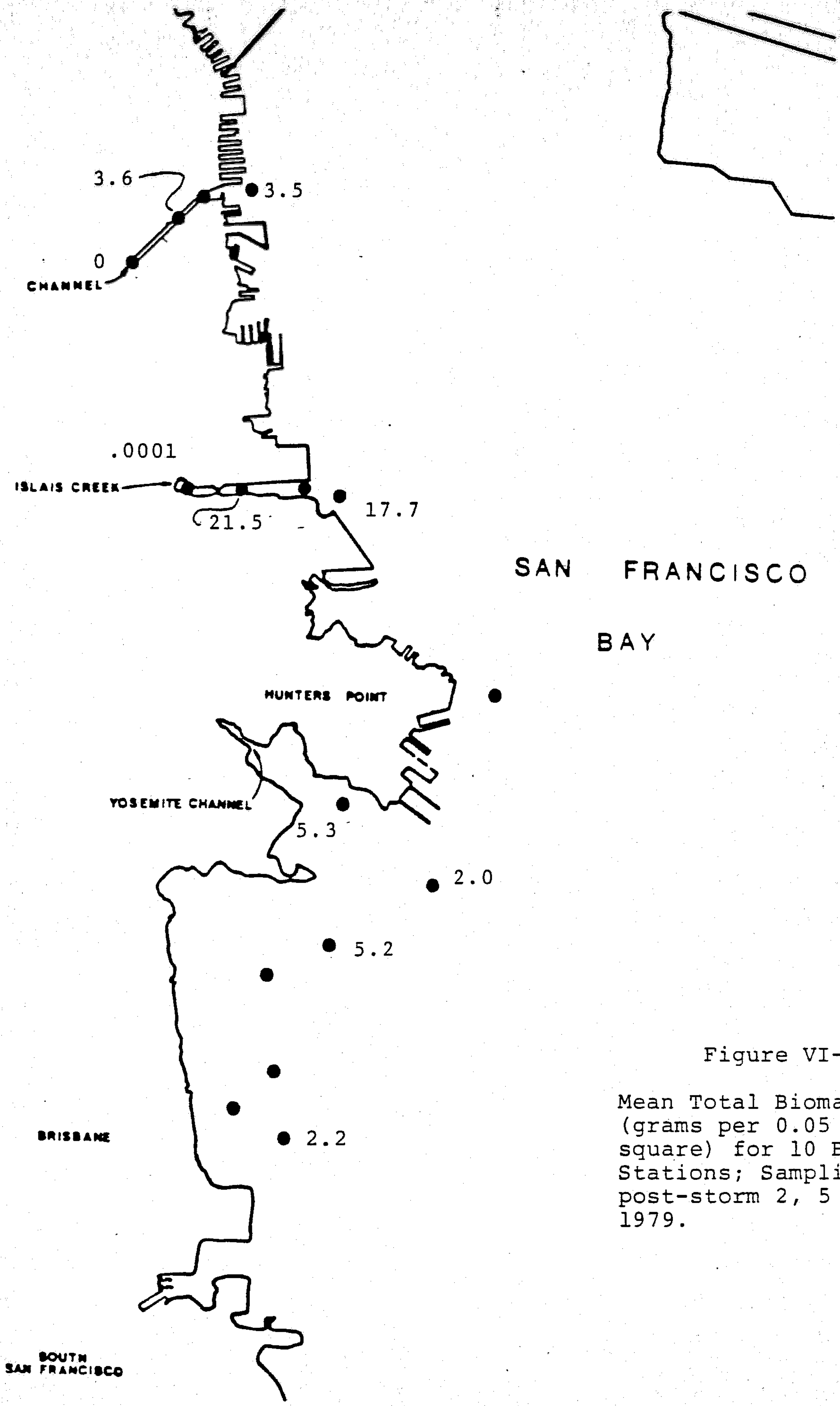


Figure VI-10

Mean Total Biomass (grams per 0.05 meter square) for 10 Benthic Stations; Sampling III, post-storm 2, 5 March 1979.

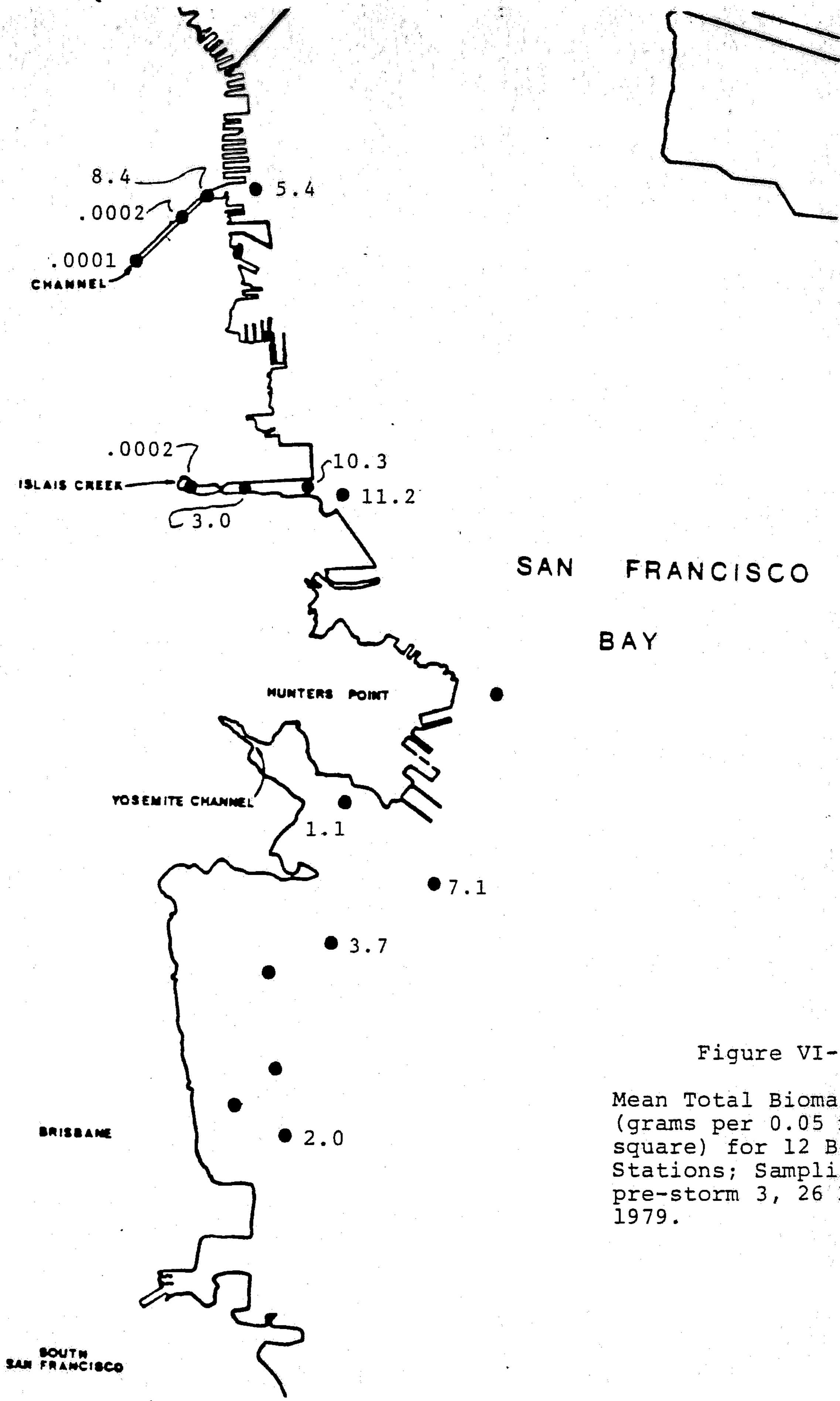


Figure VI-11

Mean Total Biomass (grams per 0.05 meter square) for 12 Benthic Stations; Sampling IV pre-storm 3, 26 March 1979.

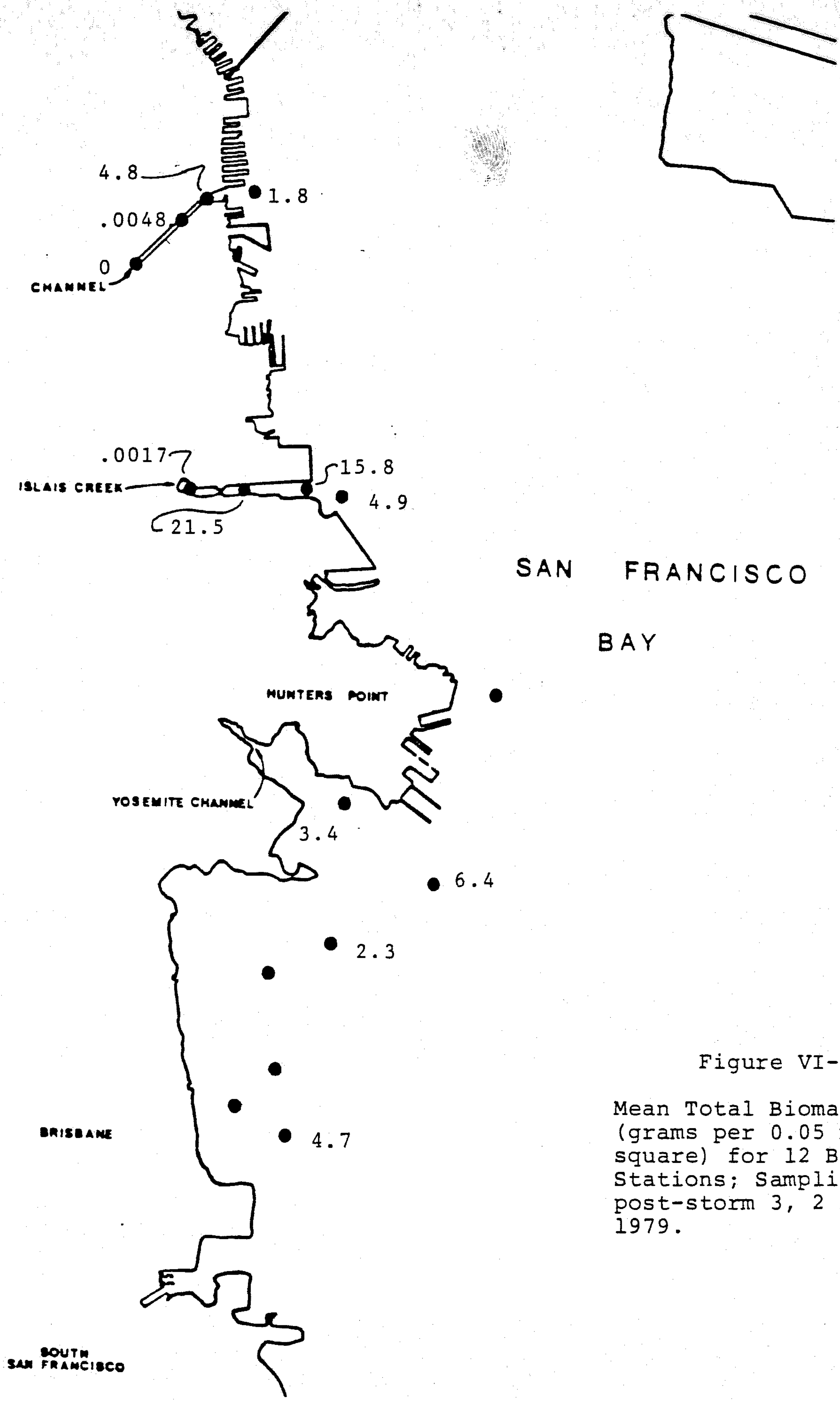


Figure VI- 12

Mean Total Biomass (grams per 0.05 meter square) for 12 Benthic Stations; Sampling V, post-storm 3, 2 April 1979.

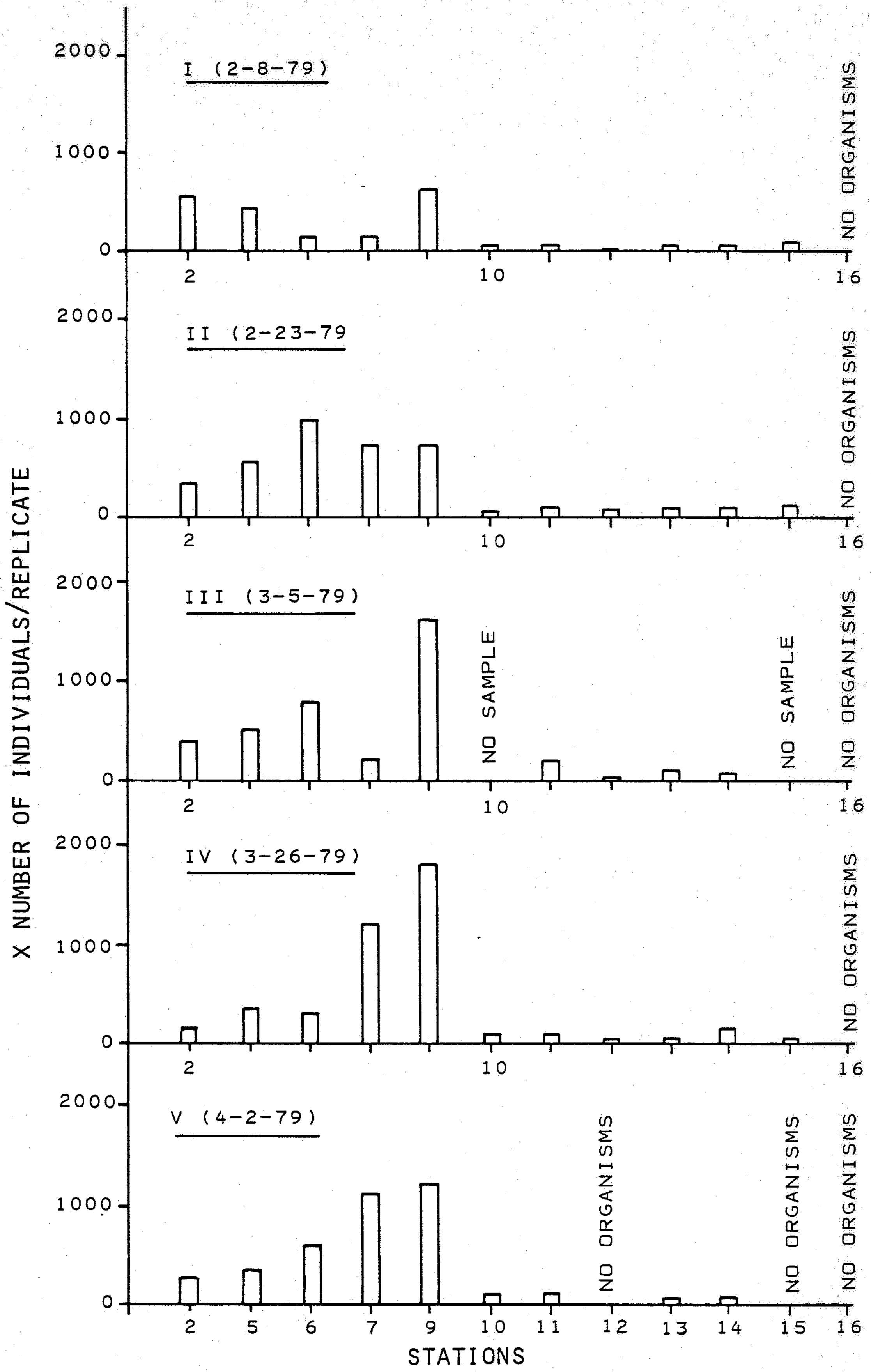


FIGURE VI-13

MEAN NUMBER OF INDIVIDUALS PER REPLICATE SAMPLE (NO. PER 0.05 METERS^2) FOR ALL STATIONS AND FIVE SAMPLING PERIODS.

CH2M HILL

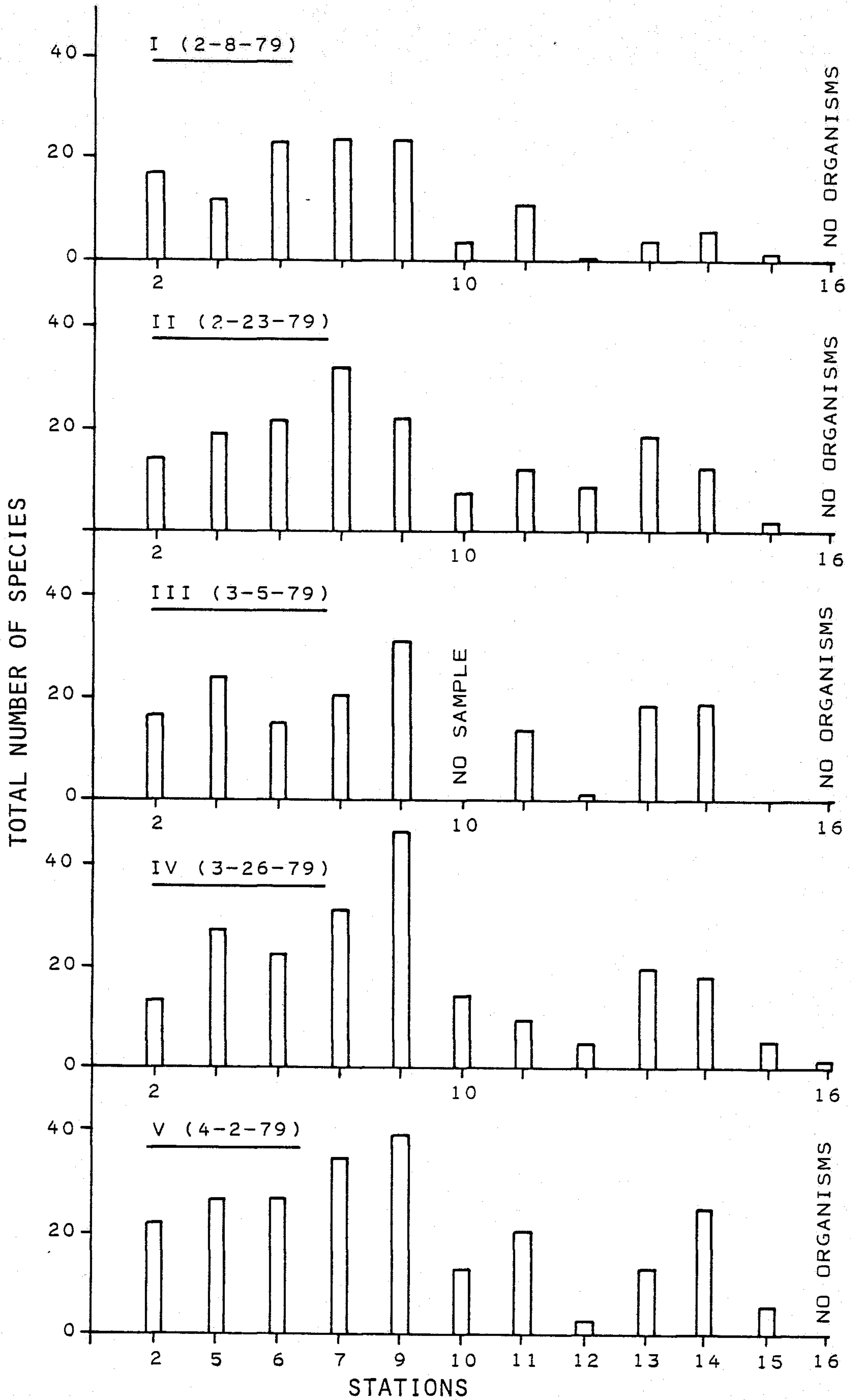


FIGURE VI-14

TOTAL NUMBER OF SPECIES PER STATION
FOR THE FIVE SAMPLING PERIODS.

CH2M HILL

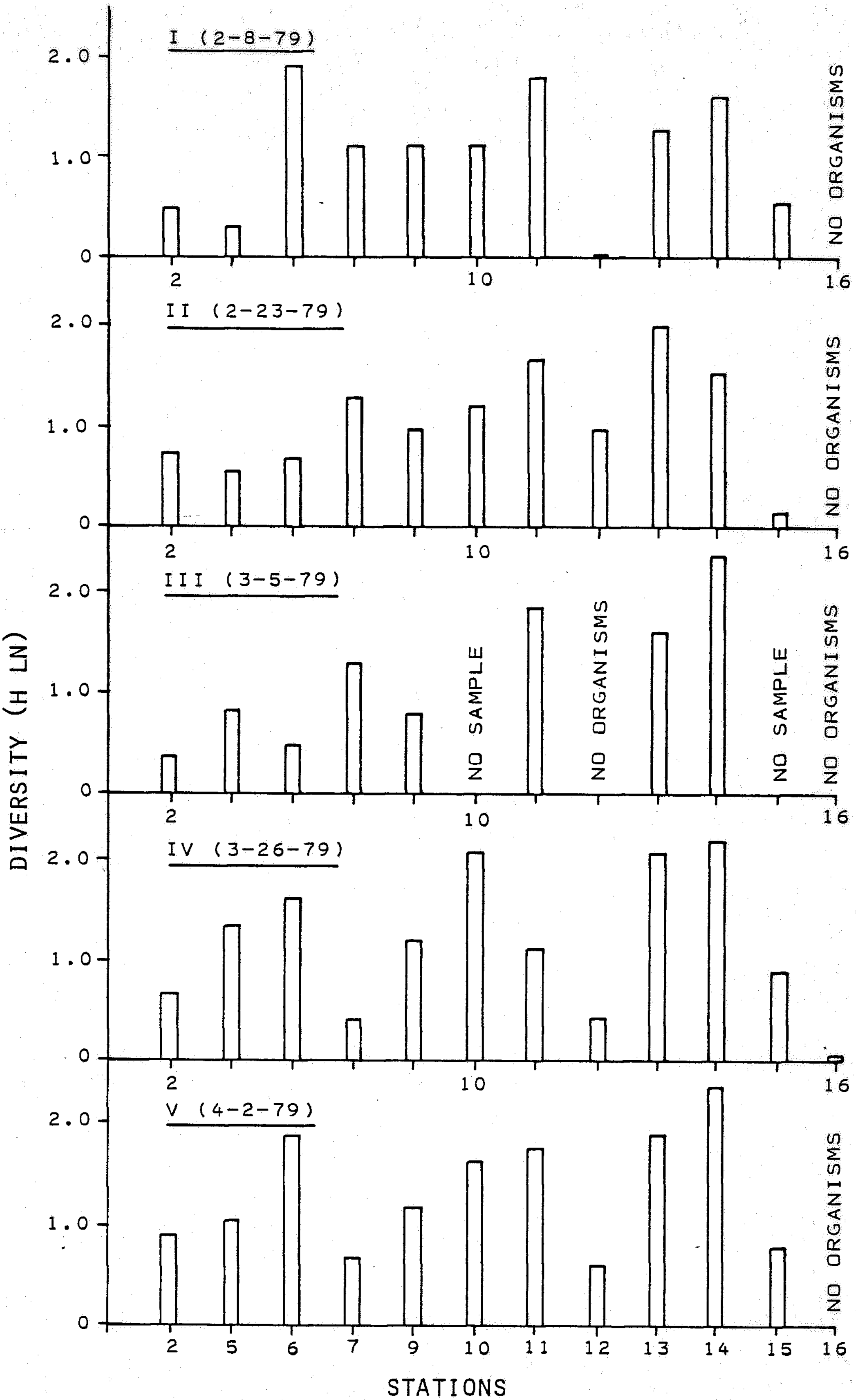


FIGURE VI-15

SHANNON-WEINER SPECIES DIVERSITY (H LN-MEAN VALUES) PER STATION FOR THE FIVE SAMPLING PERIODS.

CH2M HILL

VII. IMPACTS OF COMBINED SEWAGE OVERFLOWS ON SHELLFISH

INTRODUCTION

Shellfish have been known to accumulate and concentrate pollutants. Additionally, shellfish beds have been identified near CCSF combined sewer overflow (CSO) structures. To determine the impacts of CSO's on shellfish beds, an investigation was undertaken. It is important that the effects of CSO's be differentiated from the background levels of pollution in the Bay. The shellfish are of particular interest since a quarantine prohibiting shellfishing has been in effect since 1932. Although partially rescinded in 1934, the quarantine was re-established in 1945 until 1953. At present, shellfish tissues and overlying waters frequently violate the standards set by the National Shellfish Sanitation Program. These standards are:

- o For tissues, "the concentrations are not to exceed 230 MPN fecal coliforms per 100 gms tissue"
- o For overlying water, "the coliform median MPN of the water is not to exceed 70 per 100 ml and not more than 10 percent of the samples may exceed an MPN of 230 per 100 ml ... in those areas most probably exposed to fecal contamination during the most unfavorable hydrographic and pollution conditions."

These standards have been exceeded in all areas of the Bay (Ref. 1) including the beds sampled during this study.

Initially, seven stations were chosen for studying clams. These were Warmwater Cove, Yosemite Creek, Candlestick Cove, Candlestick Causeway North, Candlestick Causeway South, Brisbane Lagoon North and Brisbane Lagoon South (see Figure I-2 and Table I-1 for station locations). The shellfish sampling program was conducted before and after each of three rainfall events. After the first storm, CCSF requested that sampling at the Southern Causeway and the Brisbane Lagoon stations be eliminated and that another station be added at Candlestick Point. After further discussions, the sampling stations in Brisbane Lagoon were re-established. The shellfish stations selected for this study had been sampled previously by Sutton (Ref. 2), and by CCSF. Additionally, Candlestick Cove was sampled by EPA (Ref. 1) and Girvin et al. (Ref. 3). Sutton (Ref. 2) provided estimates of clam bed sizes and populations.

The Yosemite Creek station is located 300 feet southeast of the Griffith Street South overflow. Two other overflows influence this area; the Yosemite overflow and the Fitch overflow. Sutton (Ref. 2) estimated that this shellfish bed was 4,200 square feet in area and that it contained 47,000 _Tapes_. The area is heavily "polluted" with trash and broken glass, and although the clam populations are very productive, very little if any signs of clamming was noted during this study. In general, coliform levels in this area are high and were directly influenced by the adjacent overflows. Total coliform levels ranged from 2.3×10^4 to 1.1×10^7 per 100 ml; fecal coliforms from 3.0×10^3 to 2.1×10^6 per 100 ml in the Yosemite overflow and 2.4×10^4 to 2.4×10^6 (total) and 2.3×10^3 to 1.1×10^6 for fecals in the Griffith Street overflow. Brown and Caldwell (Ref. 4) found total coliform levels of 1.3×10^6 to 2.4×10^6 and fecal coliform of 1.1×10^5 to 7.9×10^5 in overlying water in this area during overflows. This station was classified as a station having maximal exposure during overflow events.

The Candlestick Cove station is located 300 feet northeast of the Sunnydale CSO. Two large highway storm drains also empty into the cove. Sutton (Ref. 2) estimated the area of this shellfish bed at 4,300 square feet with 12,000 _Tapes_. Coliform levels in this area are high and were directly influenced by the adjacent overflows. Concentrations from the overflow were as high as 7.5×10^6 per 100 ml for total and fecal coliforms. During an overflow, Bay water levels ranged from 3.5×10^6 to 7.9×10^6 per 100 ml for total coliforms and 1.1×10^5 per 100 ml to 7.9×10^5 per 100 ml for fecal coliforms (Ref. 4). This station also was classified as a station having maximal exposure during overflow events.

The Candlestick Point area receives diluted wastewater from the Sunnydale overflow. The overflow is 4,500 feet to the west. The bed is 7,850 square feet in area and contains about 47,000 _Tapes_ and 5,000 _Mya_ (Ref. 2). This station was classified as intermediate in the level of exposure to effluent.

The Candlestick Causeway North Station is located 1,600 feet north of the Brisbane Lagoon culvert and 5,000 feet south of the Sunnydale overflow. This is a large bed extending over 17,700 square feet and containing 182,000 _Tapes_ and 4,000 _Mya_ (Ref. 2). Although currents do not appear to carry the wastefield from Sunnydale this far south, the station is intermediate in distance to a CSO and was classified as intermediate in the level of exposure to CSO.

The Candlestick Causeway South station was sampled only twice. The area of this station is 19,000 square feet and includes 141,000 _Tapes_ (Ref. 2). A small portion of this area (approximately 10 percent) also contains 3,000 _Mya_. No effluent is evident in this area.

Two stations were established in Brisbane Lagoon. One was midway between the east and west sides on the northern bank, and the other was on the west bank, one-third the length of that bank from the southern end of the lagoon. The northern bank bed was estimated at 5,900 square feet in area and contained 36,000 _Tapes_ and 25,000 _Mya_, while the western bank was 48,500 square feet in area with 166,000 _Tapes_ and 76,000 _Mya_ (Ref. 2). Both areas are utilized for recreational clamming, particularly the western area which is more accessible. No combined sewer overflow influence is evident here. The nearest CSO is Sunnydale, 10,000 feet away by water. The dye studies show no evidence of the Sunnydale overflow going far enough south along the causeway to enter the lagoon through the culverts.

The Warmwater Cove station is 9,700 square feet in area and contains 27,000 _Tapes_ (Ref. 2). This area is heavily utilized for clamming and pile worms with signs of recent digging evident during all visits. _Tapes_ dominates the shellfish population although _Mya_ and _Clinocardium_ are occasionally found. There are no CSO's in the immediate area, nor are CSO effluents likely to reach this area. The nearest major CSO is in Islais Creek, 11,000 feet away by water. The Brisbane, Candlestick Causeway South and Warmwater Cove stations were classified as "control stations" having minimum exposure to CSO.

Clams were sampled during low tide by hand. Enough clams to provide adequate tissue for the bacteriological and chemical analysis were taken at each location. This typically necessitated the collection of 30 to 40 _Tapes_ of between 1 and 2 inches. Clams are washed with Bay water in the field, placed in plastic bags and transported to the laboratory cooled on ice. Clams being analyzed for metals and chlorinated hydrocarbons were normally depurated for 3 days in Bay water collected at Fort Mason. Water was replaced daily and each tank was aerated. Temperature was maintained at 16-19°C through use of a water bath. On 21 February and 2 April samples were split, with half the sample being frozen immediately and the other half being depurated before freezing and analysis.

Most samples consisted only of _Tapes japonica_. A few _Mya arenaria_ were included in some samples taken on 8 February. Restricting samples to _Tapes_ was done to prevent possible problems with data interpretation on mixed samples since the two species could have differing filtration and bacterial uptake and die-off rates. Later analysis showed no statistical difference between total coliform and fecal coliform samples in _Tapes_ and _Mya_ sampled at the same time and place. Although the lack of significant differences in this analysis lends validity to comparisons of mixed samples and samples of either species, the sample size was small.

RESULTS

Bacteriological data obtained during this study is summarized in Table VII-1. A statistical analysis of this data was performed and the results are contained in Appendix H. The data was grouped into various subsets for analysis to indicate trends. One such subset represented all stations for the entire study period. For this subset of data, there were no statistically significant (A .05 level of significance is used throughout this analysis) differences for total coliforms. These results indicate that there was no permanent or long-term effect on coliform levels from combined sewer overflows.

To determine whether there were any transient impacts, stations were grouped according to their proximity to overflow structures. Yosemite and Candlestick Cove were included as stations of maximum exposure to CSO's, while Candlestick Point and Candlestick Causeway North were intermediate in exposure to CSO's. All other stations were grouped as stations unlikely to be directly influenced by overflow points. Analysis of fecal coliform levels before storms (8 February and 26 March) showed no statistical differences between the station groups. Analysis of bacteria levels after storms (21 February and 2 April) showed statistically significant differences with the near overflow structure stations having higher fecal coliform levels than the middle and distant station groups respectively. Additionally, analysis of the differences between before and after storm data, showed the near overflow structure stations to be statistically higher than stations far from the outfalls. It is, therefore, logical to conclude that the overflows do significantly increase fecal coliform levels in clam beds within 300 feet of the overflows and do not statistically affect clam beds further away. We cannot say to what distance over 300 feet, if any, the overflows continue to have significant effects but the data does not show significant changes in two stations between 4,000 and 5,000 feet away from the Sunnydale overflow. There were only eight data points for these two stations and it is possible that more data would be needed to detect any significant change if one took place.

Bacterial levels increased sharply at all stations from 8 February to 21 February and 26 March to 2 April. This increase is attributable to rain storms occurring between these dates, and as shown in the statistical analysis, the stations nearest overflows showed increases that were significantly greater. Levels had not returned to the 8 February conditions when clams were again sampled on 6 March, though they had by 14 March. In addition, the levels on the 6th of March were on an average 40 times higher than levels on the 14th of March. This is a dramatic decrease. It therefore appears that clams can adequately purge themselves of the bacterial contamination attributable to the overflows if conditions allow (i.e., water bacteria levels decrease sufficiently and small overflows do not repeatedly occur). Therefore, even though the overflows do significantly increase clam bacteria levels in stations located within 300 feet, these stations can return to normal bacterial levels upon cessation of overflows. This is reinforced by the fact that statistical analysis of fecal bacteria taken by the City from July to November 1978 showed no significant differences between stations. Bacteria levels found during EPA's 1972 study, which included samples from Candlestick Cove, also showed no statistically significant differences between stations. Figure VII-1, which displays data from Candlestick Cove from July through April, shows both the effects of the overflows and the rapid return to near normal fecal coliform levels between overflows.

During the wet weather season there is a generalized increase in the frequency of fecal coliform standard violations. This increase is seen at almost all stations, regardless of their proximity to CSO's. Violations of the 230 MPN/100 ml water standard have also been observed in the Bay before major overflow periods.

Shellfish of various species have been shown to clear themselves of bacterial and viral contamination when placed in clean water. In natural shellfish populations, the organisms will clear themselves of high bacterial levels and return to "equilibrium" with the overlying water. The level of bacterial and viral contamination found in shellfish has been shown to be proportional to the levels in the overlying waters and uptake is essentially complete within 24 hours.

Normally, shellfish concentrate organisms 10 to 40x the ambient water level (Refs. 5, 6, 7 and 8) with a specie's specific effect noted. For example, Manila clams (*Tapes japonica*) accumulate more than Pacific oysters (*Crassostrea gigas*) and Olympia oysters (*Ostrea lurida*) (Hoff and Becker 1969). *Mya arenaria* was found to concentrate bacteria about 20 fold while the Northern quahaug (*Mercenaria mercenaria*) only concentrated them 6x (Ref. 5).

The clearing rate is dependent largely on shellfish activity, turbidity, initial concentration, salinity and temperature (Ref. 5, 8, 9 and 10) with a species specific affect also evidenced (Refs. 5 and 11).

The majority of the studies show that the elimination of viruses and bacteria is an efficient process, with low levels generally reached within 72-96 hours or less if organisms are transferred to clean water (Ref. 5, 6, 10, 11 and 12). This rate is obviously fast enough to account for the lack of statistical differences in stations near CSO during non-overflow periods and before overflows in other stations.

A factor which may tend to prolong shellfish contamination is the interaction between the sediments and the viral and bacterial input from CSO's. Bacteria and viruses tend to associate with particulate matter (Refs. 12 and 13). In addition, they tend to live longer in the sediments than when they are suspended in the water column. As a result, if bottom sediments are resuspended before their viral and bacterial levels return to background levels, sediment effects on shellfish may be observed (Refs. 3 and 8).

Along with the uptake and concentration of bacteria and viruses, shellfish also concentrate heavy metals (mercury, cadmium, nickel, silver, zinc, copper, chromium, lead arsenic, etc.) found in the ambient waters. During a 1972 survey of shellfish in San Francisco Bay, EPA (Ref. 1) found high levels of lead in undepurated clams from Candlestick Cove. These levels exceeded FDA recommended limits for foods. Girvin (Ref. 3) found considerably lower levels of lead in depurated clams from this area.

Shellfish were collected from the same stations and at the same times for metals analysis to determine whether CSO's increased metal levels in shellfish tissue. On 2 and 21 February, samples were not depurated. After that date, all samples were depurated for 3 days in aerated seawater. Samples were frozen until chemical analysis. On 21 February and 2 April, samples were split and analyzed for metal content in depurated and undepurated samples. Data for individual stations and individual dates is provided in Appendix H. Table VII-2 shows data for depurated and undepurated clam metal concentrations. Based on a two-way analysis of variance, chromium, copper, and lead concentrations were significantly higher in undepurated samples. Chromium was an average of 1.8x greater in undepurated samples, while copper was 3x and lead 1.5x higher. This analysis lead to separation of the depurated from undepurated samples for these three metals and indicates that metals in undepurated clams cannot be properly compared to depurated ones.

Data was statistically analyzed for significant changes in metal concentration through the study period at the two stations (Yosemite and Candlestick Cove) in close proximity to the CSO's. No significant differences were found, indicating a lack of metals accumulation due to CSO's. In fact, average mercury, cadmium, nickel, copper and lead levels apparently decreased through the study period.

Metals were analyzed at all stations for effects before and after storms using 8 February and 26 March as pre-overflow dates and 21 February and 6 April as after-overflow dates. These dates most successfully bracketed an overflow event. Again, no comparisons were significantly different, which also indicates a lack of metal increase due to CSOs.

Table VII-3 shows average metal concentrations for each station for both depurated and undepurated samples. This data was also analyzed statistically. Several analyses were statistically significant. Warmwater Cove had significantly more nickel and copper. It is important to note that this station is distant from any CSO. Clams at the Yosemite station had significantly more lead, although this level cannot be attributed directly to the CSO's by data collected in this study.

Table VII-4 shows the mean and standard deviations of metals found in mussels (Mytilus edulis) in the study area and in other areas of the bay (Ref. 14). None of the metals were significantly higher in the study area, indicating no distinct metal accumulation attributable to CSO's. Additionally, Girvin et al. (Ref. 3) found that Candlestick Cove and North Coyote Point were the most similar stations due to their mutual low levels of silver, cadmium, copper, mercury, lead and zinc. This similarity, based on low metal concentrations, is indication of a lack of CSO effects on tissue metals. Data collected at the water surface during overflows in 1979 show an apparent relationship between high lead levels and low salinity, with increases in lead reaching 4-5 x levels in water of normal bay salinities. These lead levels were approximately twice the concentration found by Girvin et al. (Ref. 3). But despite elevated lead levels, no increased uptake in shellfish near outfalls was noted. This is likely due to the relatively low amount of dissolved lead (usually less than 10 percent of the total) and relatively low amounts of lead typically absorbed through alimentary routes. Depurating clams significantly lowered lead levels, indicating that most the lead was in a particulate phase and not absorbed into the clam tissue.

Chlorinated hydrocarbon compounds have attracted widespread attention because of their toxic nature and their resistance to biological and chemical degradation. As a result they tend to persist in the environment and become concentrated in animal tissues.

Clams (Tapes japonica) which were collected during this study were analyzed for chlorinated hydrocarbons. (All values expressed here are for dry weight.) The results are listed in Appendix H. Most observed values were below detection limits. The highest observed PCB (Arochlor) value for clam tissue was 102 µg/kg. This level is near the mussel (Mytilus californianus) tissue values collected off Bodega Bay and the Channel Islands (Ref. 15). The values reported in this reference were between 75 and 125 µg/kg. Reported values for Mytilus edulis taken from coastal areas of the Southern California Bight averaged 440 µg/kg (Ref. 16). Riseborough et al. (Ref. 14) reported values of PCB of 290-1,500 µg/kg in mussels from San Francisco Bay. Girvin et al. (Ref. 3) found PCB (Arochlor 1254) to range from 146 to 190 µg/kg in Tapes japonica. EPA (Ref. 1) reported Arochlor 1242 and 1254 levels of 133 µg/kg for clams from Bayview Park. These reported values are higher than those observed in the clams, sampled in this study. This difference in chlorinated hydrocarbon concentration may be due to the fact that different organisms concentrate these compounds to different degrees and to some degree by different analytical techniques.

The Tapes japonica DDT tissue levels from the Bay are also very low compared to Mytilus tissue levels from other studies. The highest DDT level observed in this study was 2.1 µg/kg. The values reported by SCCWRP (Ref. 15) range from 200 to 400 µg/kg for Mytilus californianus in the offshore areas considered unaffected by outfalls. Rise-borough et al. (Ref. 4) found values of 10-100 µg/kg pp'DDE, <3-140 µg/kg pp'DDT and 20-180 µg/kg pp'DDD in mussels around the Bay. Ranges from 32.8 to 74.5 µg/kg total DDT was found in Tapes japonica from Albany Hill, Coyote Point, and Foster City (Ref. 3). EPA found levels of DDT compounds to vary from below detection (op'DDD) to 20 µg/kg (pp'DDE) with a total DDT level of 50.5 µg/kg in shellfish from Bayview Park. These comparisons suggest that the levels of chlorinated hydrocarbons in clam tissues in the Bay are low and that CSO's do not have an impact on TICH levels.

Sediment samples were collected at several shellfish beds for metal, total organic carbon, oil and grease, percent hydrocarbons, particle size distributions, total sulfide, and chlorinated hydrocarbons (Arochlors, dieldrin, pp'DDE, pp'DDD, pp'DDT, op DDT, and op DDD). Samples were collected on March 8, 14, 26 and April 2. Overflow events occurred on February 28 and March 26-27. Therefore, only data collected on March 26 and April 2 bracket an overflow event. For this reason, analysis of the sediment data differs from analysis of clam tissue data. A one-way analysis of variances was performed to indicate trends in the data. The results are listed in Appendix H and summarized in Table VII-5. The majority of the statistical analyses indicated that there were few trends due to station, proximity to outfalls or sampling dates.

When the data was segregated by dates, the statistical analysis indicated that only arsenic and the grain size fraction <2μm showed significant differences. Both variables were highest on March 14 and lower on March 26. Both these dates represent before storm events. Arsenic increased after one storm, while grain size <2μm continued to decrease.

As a check on the influence of a single overflow event on stations located near overflow structures, samples taken at Candlestick Cove and Yosemite on March 26 and April 2 were compared by t-test. No significant differences were found by this analysis.

In comparison with the clam tissue analysis, chemical-physical data for sediments at the clam stations proved not to be a good indicator for detecting differences resulting from CSO's. This is due to the fewer dates sampled. In summary, sediment characteristics were unique for each station, regardless of their proximity to overflow structures.

<u>SUMMARY</u>

Statistically significant increases in shellfish fecal coliform levels occurred within 300 feet of overflow structures. No changes attributable to CSO occurred in other shellfish beds although their fecal coliform content also increased. Shellfish beds have the ability to purge themselves of bacteria and viruses. This is an efficient process, with low levels reached within 72-96 hours or less, once the source of pollution is removed. Historical data reveals that shellfish standards are exceeded by all beds in the study area during the rainy season. The evidence indicates that removal of CSO's would not make shellfish harvestable.

No evidence was found for CSO having any detectable additional effect on shellfish heavy metal content.

Most chlorinated hydrocarbon levels in shellfish tissue were below detectable limits.

Sediment characteristics were unique at each shellfish station. There does not appear to be a relationship between sediment characteristics and combined sewer overflows.

References

1. Environmental Protection Agency. June 1974. Shellfish Study of San Francisco Bay April-June 1972 Technical Report, U.S. EPA, Region IX. Surveillance and Analysis Division, San Francisco, California EPA 909/9-74-003.

2. Sutton, James E. December 1978. Survey of Sport Shellfishing Potential in San Francisco Bay, in Southern San Francisco and Northern San Mateo Counties. Final Report. San Francisco Wastewater Program. City and County of San Francisco.

3. Girvin, D.C., A.T. Hodgson, M.H. Panietz. November 1975. Assessment of Trace Metal and Chlorinated Hydrocarbon Contamination in Selected San Francisco Bay Estuary Shellfish. Final Report. Energy and Environment Division, Lawrence Berkeley Laboratory University of California.

4. Brown and Caldwell. June 1979. Unpublished data collected for the Wastewater Program, City and County of San Francisco.

5. Cabelli, V.J., and W.P. Heffernan. 1970. Elimination of bacteria by the soft shell clam, Mya arenaria. J. Fish Res. Board, Canada. 27(9):1579-1587.

6. Mitchell, J.R. et al. 1966. Accumulation and elimination of poliovirus by the Eastern oyster. Amer. J. Epid. 84:40-50.

7. Kelley, S., and W.W. Sanderson. 1960. Density of enterovirus in sewage. J.W.P.C. Fed. 32:1269-1274.

8. Hoff, J.C., and W.J. Beck. 1968. The accumulation and elimination of crude and clarified poliovirus suspensions by shellfish. Amer. J. Epid. 80:53-61.

9. Metcalf, T.G., and W.C. Stiles. 1966. Survival of eNteric viruses in estuary water and shellfish. In. G. Berg (ed.). Transmission of Viruses by the Water Route. Interscience, New York.

10. Arcisz, W. and C.B. Kelley. 1955. Self-purification in the soft clam Mya arenaria. Pub. Hlth. Repts. 70(6):605-614.

11. Liu, O.C., H.R. Seraichekas and B.L. Murphy. 1967. Viral pollution and self-cleansing mechanism of hard clams. In G. Berg (ed.). Transmission of Viruses by the Water Route. Interscience New York.

Table VII-1

TISSUE BACTERIAL LEVELS OF CLAM SAMPLES

Station	Analysis	Date Sampled: 8 February	21 February	6 March	14 March	26 March	2 April
Yosemite Creek	Fecal coliform	230	92,000	9,200	210	1,400	5,400
	Total coliform	4,600	NA	NA	24,000	5,400	92,000
	Standard plate count	NA	310,000	17,000	NA	NA	17,000
Candlestick Cove	Fecal coliform	150	240,000	490	150	278	92,000
	Total coliform	930	NA	NA	4,600	1,720	92,000
	Standard plate count	NA	770,000	17,000	NA	NA	14,000
Candlestick Point	Fecal coliform	NS	NS	9,200	40	NA	330
	Total coliform	NS	NS	NA	930	NA	1,100
	Standard plate count	NS	NS	26,000	NA	NA	4,300
Candlestick Causeway North	Fecal coliform	30	1,700	310	40	NA	490
	Total coliform	2,400	NA	NA	390	NA	9,200
	Standard plate count	NA	13,000	27,000	NA	NA	1,000
Warmwater Cove	Fecal coliform	390	5,400	790	40	20	170
	Total coliform	1,500	NA	NA	210	918	9,200
	Standard plate count	NA	18,000	26,000	NA	NA	8,500
Brisbane Lagoon North	Fecal coliform	90	9,200	NS	150	240	330
	Total coliform	110	NA	NS	2,400	540	7,000
	Standard plate count	NA	37,000	NS	NA	NA	5,200
Brisbane Lagoon West	Fecal coliform	30	2,400	NS	40	221	490
	Total coliform	230	NA	NS	150	24,000	2,400
	Standard plate count	NA	16,000	NS	NA	NA	1,400
Candlestick Causeway South	Fecal coliform	30	5,400	NS	NS	NS	NS
	Total coliform	90	NA	NS	NS	NS	NS
	Standard plate count	NA	10,000	NS	NS	NS	NS

NOTE: Fecal and total coliforms as MPN/100 gm wet tissue, standard plate count as no/gm. Analysis on 21 February, 6 March and 2 April by CCSF, Public Health Laboratory. Other analysis by LFE Environmental Laboratory, Richmond.

NS = not sampled; NA = not analyzed for that measure

Storm dates: February 13, 15, 16, 18, 20, 21, 22, 23, 25, 28
March 3, 15, 16, 26, 27

12. Hamblett, F.E., W.F. Hill Jr., E.W. Akin, and W.H. Benton. 1969. Oysters and human viruses: Effect of seawater turbidity of poliovirus uptake and elimination. _Amer_. _J_. _Epid_. 89(5):562-571.

13. Smith, E.M., C.P. Gerba, and J.L. Melnick. 1978. Role of sediment in the persistence of enteroviruses in the estuarine environment. _Appl_. _and_ _Environ_. _Microbiology_. 35(4):685-689.

14. Riseborough, R.W., J.W. Chapman, R.K. Okazaki, and T.T. Schmidt. 1978. Toxicants in San Francisco Bay and Estuary. Report to Association of Bay Area Governments, Berkeley, by Bodega Bay Institute of Pollution Ecology.

15. SCCWRP. 1973. The Ecology of the Southern California Bight: Implications for Water Quality Management. Southern California Water Research Project.

16. Young. D.R. and G.V. Alexander. 1977. Metals in Mussells from Harbors and Outfall Areas. In Annual Report. Coastal Water Research Project, El Segundo, California.

Table VII-2

TRACE METAL CONCENTRATIONS
IN DEPURATED AND UNDEPURATED CLAM TISSUE

		Mercury	Cadmium	Chromium	Copper	Lead	Nickel	Silver	Zinc
Depurated	Mean	.23	1.5	.76	9.2	11	17	.36	131
	Std. Dev.	.13	.59	.14	.53	17	8	.16	31
Undepurated	Mean	.32	1.6	1.4	28	17	18	.45	139
	Std. Dev.	.28	.95	1.3	32	19	8	.17	32
Result of 2-way analysis of varience		NS	NS	S	S	S	NS	NS	NS

Notes:

1. All concentrations are mg/kg dry weight
2. Samples collected on 21 February and 2 April 1979
3. NS - Not significant
4. S - Significant

Table VII-3

AVERAGE LEVELS OF TRACE METALS IN CLAM TISSUES

Station/Preparation		METALS (mg/kg dry weight)															
		Mercury		Cadmium		Nickel		Silver		Zinc		Copper		Chromium		Lead	
		$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Yosemite	D&U	.16	.09	1.6	.68	15	4.9	.15	.002	160	35	19	19	1.3	1.5	45.3	7.1
	D	.15	.08	1.4	.70	13	4.2	.15	0	150	36	12	9.0	.51	.30	42	6.0*
Candlestick Cove	D&U	.34	.19	1.6	.55	18	4.3	.36	.21	120	21	13	6.8	.78	.31	7.3	5.1
	D	.28	.12	1.7	.23	19	3.5	.23	.10	130	18	13	8.0	.82	.21	7.7	3.6
Candlestick Point	D&U	.24	.02	1.6	.23	19	5.4	.33	.13	150	31	13	5.0	.65	.28	2.5	0
	D	.24	.02	1.6	.24	19	5.4	.33	.13	150	31	13	5.0	.65	.28	2.5	0
Candlestick Causeway-N	D&U	.23	.11	1.4	.47	16	5.3	.65	.23	130	26	13	5.3	.77	.25	4.6	3.0
	D	.22	.08	1.6	.35	14	5.1	.66	.27	120	20	10	4.0	.74	.33	2.5	0
Warmwater Cove	D&U	.79	.99	2.1	1.1	31*	14	5.3	13	120	55	51*	41	3.8	8.0	8.4	4.9
	D	.87	1.2	1.9	1.3	30*	16	7.2	15	110	63	45*	43	5.0	9.5	7.2	5.5
Brisbane Lagoon North	D&U	.18	.09	1.4	.12	12	4.9	.44	.10	110	21	14	10	.60	.34	3.4	2.2
	D	.14	.08	1.3	.05	9.1	3.2	.42	.09	100	20	10	3.3	.41	.19	2.5	0
Brisbane Lagoon South	D&U	.24	.53	1.3	.64	13	5.2	.44	.20	120	22	18	12	.73	.11	4.3	3.1
	D	.21	.02	.92	.51	11	6.1	.57	.15	110	26	11	5.7	.69	.09	2.5	0
Candlestick Causeway-S	D&U	.31	.11	2.1	.66	17	3	.32	.15	150	13	15	5.8	.63	.33	6.0	3.1
	D	.28	-	2.8	-	14	-	.35	-	140	-	9.5	-	.25	-	2.5	-
Limits of detection		~.13		1				.3						.5		5	

NOTES:

1. D = Depurated samples
2. U = Undepurated samples
3. x = Mean
4. S.D. = Standard Deviation

*Statistically significant

Table VII-4

HEAVY METALS AND TRACE ELEMENTS
IN MUSSELS (*Mytilus edulis*) COLLECTED IN SAN FRANCISCO BAY,

Trace Elements (mg/kg) dry weight)	All other areas of S.F. Bay (All over Bay)[1]		CSO Study Area (Bay along Study Area)[2]	
	Mean	Standard Deviation	Mean	Standard Deviation
Hg	0.39	0.22	0.45	0.130
Ag	0.51	0.41	0.33	0.18
Cd	4.7	2.52	4.5	2.4
Cr[c]	2.9	1.3	4.1	1.3
Mn	36	39	26	12
Fe	280	350	450	390
Ni	2.5	1.4	2.4	1.03
Cu	7.8	2.6	7.7	2.4
Zn	160	52	190	89
As	6.5	1.3	8.0	1.7
Pb	4.2	6.7	2.6	1.3
Se	3.5	1.3	3.6	0.91
Br	290	98	270	62
Rb	2.3	0.89	2.4	0.78

NOTES FOR TABLE VII-4

[1]All Other Areas of San Francisco Bay:

- S.E. side of Brothers Light
- Richmond San Rafael Bridge, on wooden fender inside pylon w. of e. channel
- Buoy 6, Sausalito Channel dolphin
- Buoy 6, San Francisco Bay
- Berkeley Pier, approx. 100 yards from outer end, off wood
- Berkeley Marina
- Fort Baker, dolphin just west of pier, between pier and by rock
- Treasure Island
- Entrance to Oakland Outer Harbor, wooden pile
- Coyote Point
- San Mateo Bridge, west side of highest pylon
- Channel market #12, out from Redwood City, 1.5 mi. south of San Mateo Bridge
- Buoy market #5, tower #5 entrance to Redwood City Harbor
- Redwood City Harbor
- First support tower west of Dumbarton Br.
- Railroad bridge, first support west of drawbridge

[2]CSO Study Area:

- Cement piling 1.5 mi. south of Bay Bridge
- Hunters Point
- Channel buoy #2
- Channel marker #4 (red)
- Channel marker #8
- Oyster Point

NOTES FOR TABLE VII-4

[3]Collected by Riseborough, 24-25 April 1976

[4]Station selection based on salinity measurement, range 24-28 ppt.

Table VII-5

SEDIMENT CHEMISTRY AT SHELLFISH STATIONS

		Station H Warmwater Cove	Station G Yosemite	Station F Candlestick Point	Station E Candlestick Cove	Station D Candlestick Causeway North	Station B Brisbane North	Station A Brisbane West
METALS mg/kg dry wt.								
Cadmium	Mean	1.7	2.4	1.6	1.7	1.6	1.7	1.7
	Std. Dev.	0.5	0.5	0.4	0.5	0.1	-	-
Chromium	Mean	164	134	153	115	83	130	78
	Std. Dev.	68	46	34	39	38	-	-
Copper	Mean	50	153	58	74	48	61	37
	Std. Dev.	22	22	62	22	7	-	-
Lead	Mean	139	263	47	99	43	46	53
	Std. Dev.	130	36	24	48	17	-	-
Nickel	Mean	343	63	290	80	74	100	48
	Std. Dev.	207	10	151	27	29	-	-
Zinc	Mean	431	283	93	2,195	95	160	120
	Std. Dev.	647	175	20	4,137	4	-	-
Silver	Mean	0.6	0.35	0.35	0.6	<0.7	<0.7	<0.7
	Std. Dev.	0.4	0	0	0.4	0	-	-
Arsenic	Mean	3.0	1.8	2.6	3.1	4.5	6.3	3.9
	Std. Dev.	0.8	0.3	2.0	1.4	1.2	-	-
Mercury	Mean	0.28	0.47	0.22	0.22	<0.12	0.34	0.32
	Std. Dev.	0.12	0.15	0.12	0.05	0	-	-
Total Organic Carbon	Mean	4.19	1.47	0.49	3.15	1.28	1.35	0.81
	Std. Dev.	4.69	0.99	0.25	1.71	0.12	-	-
Oil and Grease	Mean	3,250	2,600	823	2,450	1,663	470	614
	Std. Dev.	436	757	403	1,797	990	-	-
Hydrocarbons (%)	Mean	50	58	37	36	36	76	68
	Std. Dev.	7	22	10	8	11	-	-
PARTICLE SIZE DISTRIBUTION								
% >62μ	Mean	66.6	82.2	76.5	77.1	51.3	79.3	68.7
	Std. Dev.	14.4	6.9	16.5	7.5	38.7	-	-
% 2-62μ	Mean	24.9	11.0	13.5	14.3	29.1	8.1	17.8
	Std. Dev.	10.0	6.8	10.6	4.8	20.7	-	-
% <2μ	Mean	8.6	6.9	10.2	8.6	19.7	12.7	13.6
	Std. Dev.	6.8	1.6	6.4	4.7	18.1	-	-
TOTAL SULFIDE								
mg/kg wet weight	Mean	485	455	14	110	5	14	17
	Std. Dev.	64	50	1	15	1	-	-
mg/kg dry weight	Mean	740	660	24	150	9	22	26
	Std. Dev.	141	71	0	14	3	-	-
CHLORINATED HYDROCARBONS mg/kg dry weight								
AROCHLOR (PCB)	Mean	6	16	20	<5	<5	<5	<5
	Std. Dev.	7	11	34	0	0	-	-
DIELDRIN	Mean	<1	<1	<1	<1	<1	<1	<1
	Std. Dev.	0	0	0	0	0	-	-
pp'DDE	Mean	<1	3.9	<1	<1	<1	<1	<1
	Std. Dev.	0	4.0	0	0	0	-	-
pp'DDD	Mean	<1	0.9	<1	<1	<1	<1	<1
	Std. Dev.	0	0.7	0	0	0	-	-
pp'DDT	Mean	1.4	4.6	0.8	5	<1	26	<1
	Std. Dev.	1.8	4.8	0.6	5	0	-	-
op DDT	Mean	<1	<1	<1	<1	<1	<1	<1
	Std. Dev.	0	0	0	0	0	-	-
op DDD	Mean	<1	<1	<1	<1	<1	<1	<1
	Std. Dev.	0	0	0	0	0	-	-

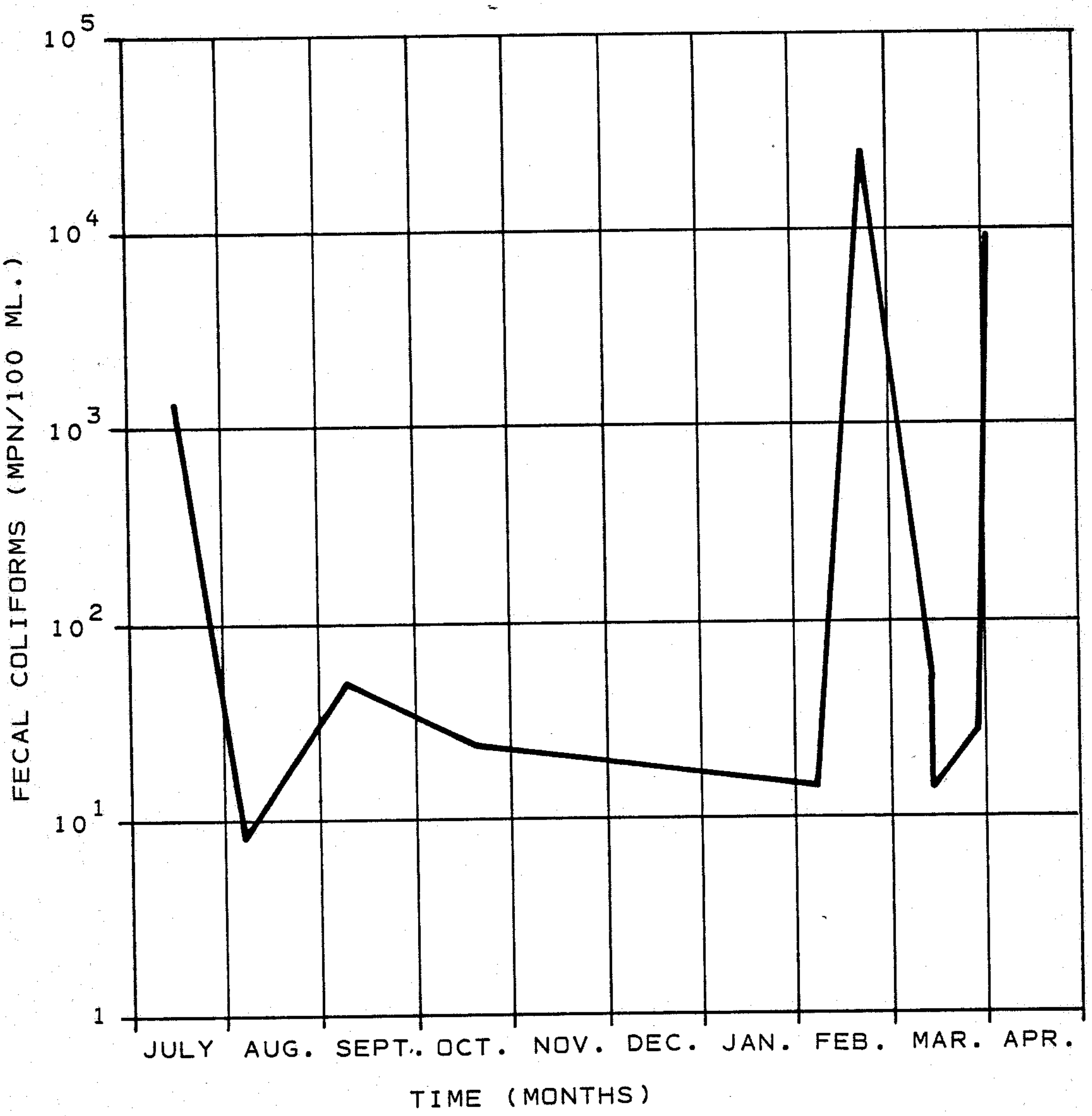


FIGURE VII – 1

CANDLESTICK COVE CLAM TISSUE FECAL COLIFORMS
JULY 1978 THROUGH APRIL 1979

CH2M HILL

VIII. FISH POPULATIONS IN OVERFLOW AREAS

INTRODUCTION

Fish trawl investigations were undertaken to obtain information on the composition of the fish community near combined sewer overflows on the bayside of San Francisco. The sampling was conducted on 6 April 1979, which was 8 days after the end of the third overflow survey.

Six stations were sampled by trawling. Station locations were chosen on the basis of depth, sediment type, and location of overflow discharge points (Figure VIII-1). The bottom trawls were made with a 25-foot otterboard trawl net. The body of the net was constructed of 1-1/2 inch stretch mesh with 1/2-inch stretch mesh liner in the cod end.

Trawl speeds were generally 1 knot. Trawling time varied between 5 minutes and 28 minutes depending on the abundance of fish.

All organisms collected in each bottom trawl were placed in labeled sacks. The sacks were iced and transported to the laboratory. On 7 April 1979 the fish were sorted to species by station. Identifications were made and confirmed by reference to Miller and Lea (Ref. 1). Each fish was examined for external signs of disease and parasitism, including fin erosion, tumors, deformities and other anamolies. Each fish was measured for total length (i.e., the tip of the snout to the tip of the tail) and standard length (i.e., the tip of the snout to the end of the vertebral column). Weight data were also taken on all fish except some smaller specimens and some individuals of the more abundant species. The liver weight was determined for the larger individuals of the more abundant species. In addition, heavy metal levels in two tissues (liver and muscle) were also measured for two fish species.

RESULTS

Nineteen species of fish, representing thirteen families, were collected in the trawls. A complete taxonomic list of the species of fish collected is given in Table VIII-1. All information collected is summarized in Appendix I.

A total of 811 fish were collected. The five most abundant species comprised 88 percent of the catch (Table VIII-2). These species in order of decreasing abundance are Northern anchovy, English sole, Pacific herring, Shiner surfperch, and Speckled sanddab.

The station outside of Channel yielded the greatest catch per effort for both total number or individuals (32.6/minute trawl) and total weight (357g/minute trawl). The stations inside Channel and inside Islais yielded small catches per effort for total weight. The station inside Channel also had the smallest catch per effort for number of individuals with nine specimens obtained in 5 minutes of trawling.

The stations inside Channel and inside Islais had the fewest number of species collected (four and two respectively). The remainder of the stations had between nine and 12 species.

The average weight of fish caught in this survey was 21.4g. All of the length and weight data collected are in Appendix I. Total length frequency distributions were constructed for English sole and Shiner surfperch (Figure VIII-2) for Channel outside, Islais outside, Yosemite, and Sunnydale. Insufficient numbers of fish were collected inside Channel and inside Islais to construct length frequency distributions for those stations. There does not appear to be a significant difference in size distribution between stations although sample size is too small to make any refined judgments.

No abnormalities were observed on any of the fish collected in this survey.

Metal levels were measured in muscle and liver tissue of English sole and Staghorn sculpin at two stations; outside Islais Creek and outside Channel (Mission Creek). In most cases, individual tissue samples were composited due to the small size of the fish. The heavy metal data is listed in Appendix I and summarized in Tables VIII-3 and VIII-4. There were no statistically significant (.05 significance level) differences between each species of fish at the two stations.

A comparison of the heavy metal tissue concentrations was made with other studies (Refs. 3 and 4). The fish sampled in this study exhibited both higher and lower metal levels. Chromium, lead and zinc levels outside Channel and Islais are higher than levels found in White croaker, Pacific sanddab, Scorpion fish, halibut, bocaccio, and kelp bass in the Southern California coastal area. The fish tissues exhibited comparable levels of copper and zinc in Dover sole from Southern California and starry flounder from Washington, but had higher lead and chromium concentrations than these fish samples. The sources of these differences is impossible to decipher, however, since species specific differences in feeding and metal uptake is involved. Fish trawl investigations were conducted only after the third overflow. The data base is too limited to determine whether combined sewer overflows from San Francisco had a direct impact on heavy metal concentrations in fish tissue.

The most striking result of this survey is the great difference in abundance and species composition between the two stations inside Islais and Channel and the remaining four stations. The inside stations are very species poor and, except for the large number of very small Northern anchovy found inside Islais, have very few individuals.

The cause of this difference is probably related to characteristics of the bottom habitat. The two inside stations are both in areas where the sediments are influenced by the combined wastewater overflow. These influences include high organic content, presence of junk and trash, higher concentrations of cadmium, copper, lead, chromium, zinc, and grease and oil, and a paucity of benthic invertebrates. The sediments in these areas are therefore suboptimal for most fish species. The effect on the fish of changes in water quality due to overflow is probably minimal because the wastewater plume is confined to the upper several feet of the water column and it can be avoided by the fish. It appears that the wastewater overflow may affect fish populations inside Islais and inside Channel by changing sediment characteristics through settling of particulate matter in the wastewater. The bottom fish at the stations outside Islais, outside Channel, near Yosemite, and near Sunnydale appear to be relatively unaffected by wastewater overflow. The species composition of these stations is similar to that found by Brown and Caldwell (Ref. 2). During that study, 34 species were found with the five most abundant species accounting for 76 percent of the catch. Northern anchovy, speckled sanddab, shiner surfperch, brown rockfish, English sole and Pacific herring were the most abundant species. Brown rockfish were only caught outside of Islais during the 6 April 1979 trawls, which accounts for their lower contribution to the total catch. The high abundance of Speckled sanddab was due to numerous very small individuals particularly those caught outside of Channel. No changes due to the CSO's are particularly indicated by these minor changes in species composition.

SUMMARY

There was a great difference in abundance and species composition between the two stations inside Islais Creek and Channel and the four remaining stations (outside Islais Creek and Channel and near Sunnydale and Yosemite). The inside stations are very species poor and had few individuals. This was attributed to the characteristics of the bottom habitat which appears suboptimal for most species. The bottom fish at the outside stations were unaffected by the wastewater overflow. No abnormalities were observed on any of the fish collected in this survey. There was no evidence indicating that combined sewer overflows had a direct impact on heavy metal concentrations in fish tissues.

References

1. Miller, D.J. and R.N. Lea. 1972. Guide to the Coastal Marine Fishes of California Department of Fish and Game. Fish Bulletin 157.

2. Brown and Caldwell. 1975. Marine Waste Disposal.

3. Jan, Moore, and Young. 1977. Tsu-Kai Jan, M.D. Moore, and D.R. Young. 1977. Metals in Seafoods near Outfalls In Southern California Coastal Water Research Project, Annual Report, 1977.

4. Marjorie Sherwood. 1977. Fin erosion disease and liver chemistry, Los Angeles and Seattle. In Southern California Coastal Water Research Project, Annual Report, 1977.

Table VIII-1

TAXONOMIC LIST OF FISH SPECIES

Scientific Name	Common Name
Clupeidae	
Clupea harengus	Pacific herring
Engraulididae	
Engraulis mordax	Northern anchovy
	Juv. anchovy
Osmeridae	
Spirinchus starksi	Night smelt
Batrachoididae	
Porichthys notatus	Plainfin midshipman
Gadidae	
Microgadus proximus	Pacific tomcod
Syngnathidae	
Syngnathus sp	Pipefish
Scorpaenidae	
Sebastes auriculatus	Brown rockfish
Cottidae	
Leptocottus armatus	Staghorn sculpin
Sciaenidae	
Genyonemus lineatus	White croaker
Embiotocidae	
Cymatogaster aggregata	Shiner surfperch
Phanerodon furcatus	White surfperch
Gobiidae	
Acanthogobius flavimanus	Yellowfin goby
Lepidogobius lepidus	Bay goby
Bothidae	
Paralichthys californicus	California halibut
Citharichthys sordidus	Pacific sanddab
Citharichthys stigmaeus	Speckled sanddab
Pleuronectidae	
Platichthys stellatus	Starry flounder
Parophrys vetulus	English sole
Hypsopsetta guttulata	Diamond turbot

Table VIII-2

Fish Weight and Abundance Summary

STATION:	Channel Inside		Channel Outside		Islais Inside		Islais Outside		Yosemite		Sunnydale		Total	
Number of Trawls	1		1		1		1		2		3			
Total Trawl Time	5 min.		5 min.		5 min.		9 min.		25 min.		38 min.			
	#	wt(g)	#	wt(g)	#	wt(g)	#	wt(g)	#	wt(g)	#	wt(g)	#	wt(g)
English sole			63	637.1*			34	983.9	10	36.5	28	144.4	135	1,801.9
Pacific herring	1	4.7							118	34.9			119	39.6
Shiner surfperch	5	75.7	53	683.5*			20	251.2	39	786.9			117	1,797.3
Northern anchovy	2	5.0	5	23.6	86	416.9	4	38.2					97	483.7
juv. northern anchovy									29	8.9	17.7	64	206	72.9
Speckled sanddab	1	6.8	26	62.5*	1	5.9	6	38.9	3	4.6	8	17.8	45	136.5
Night smelt			1	2.2	1	4.1	18	97.6					20	103.9
Staghorn sculpin			2	15.2			6	285.2	8	32.7			16	333.1
Bay goby			6	18.5							7	13.7	13	32.2
Starry flounder									4	3,751.2	3	4,245	7	7,996.2
Brown rockfish							5	78.8					5	78.8
White surfperch											5	1,339	5	1,339.
Plainfin midshipman			1	154.3			3	227.7					4	382.
Pacific tomcod			3	44.6			1	41.5					4	86.1
California halibut			1	144.0					1	152.8	3	1,664.3	5	1,961.1
Pipefish			1	1.6					2	3.8			3	5.4
White croaker							3	145.7					3	145.7
Yellowfin goby			1	—			2	54.0			2	—	5	54.0
Diamond turbot											1	500	1	500.0
Pacific sanddab											1	26.2	1	26.2
Total individuals - weight	9	92.2	163	1,787.1	88	426.9	102	2,242.9	214	4,812.3	235	8,014.4	811	17,375.8
Total # species	4		12		3		11		9		9		19	
Catch/min.	1.8	18.4	32.6	357.4	17.6	85.4	11.3	249.2	8.56	240.9	6.3	210.9		
# Adult fish - weight	9	92.2	163	1,787.1	88	426.9	102	2,242.9	185	4,803.4	65	7,950.4	605	17,302.9
# Adult sp.	4		12		2		11		8		8		19	
Catch/min.	1.8	18.4	32.6	357.4	17.6	85.4	11.3	249.2	7.4	240.5	1.7	209.2		

*Estimated biomass.

Table VIII-3

HEAVY METAL TISSUE LEVELS - ENGLISH SOLE

		Outside Islais Creek		Outside Channel	
		Muscle	Liver	Muscle	Liver
Cadmium	Mean	0.18	5.8	<0.15	3.1
	Std. Dev.	0.11	9.7	0	4.1
Chromium	Mean	2.5	7.1	3.6	3.3
	Std. Dev.	1.2	1.9	0.8	1.1
Copper	Mean	1.9	2.6	2.0	2.2
	Std. Dev.	0.5	2.5	0.2	1.7
Lead	Mean	6.1	1.7	4.1	1.5
	Std. Dev.	1.3	0.9	2.5	0.7
Nickel	Mean	<2.0	<2.0	<2.0	<2.0
	Std. Dev.	0	0	0	0
Zinc	Mean	27	111	27	105
	Std. Dev.	3.5	89	1.5	106
Silver	Mean	<0.2	<0.25	<0.2	<0.25
	Std. Dev.	0	0	0	0
Arsenic	Mean	<0.2	<0.25	<0.2	<0.25
	Std. Dev.	0	0	0	0
Mercury	Mean	0.24	0.30	0.74	0.36
	Std. Dev.	0.21	0.07	0.58	0.06

NOTE: All heavy metal concentrations are expressed in units of mg/kg dry weight.

Table VIII-4

HEAVY METAL TISSUE LEVELS - STAGHORN SCULPIN

		Outside Islais Creek	Outside Channel
		Muscle	Muscle
Cadmium	Mean	<0.15	<0.15
	Std. Dev.	0	--
Chromium	Mean	2.4	3.4
	Std. Dev.	2.2	--
Copper	Mean	2.9	2.5
	Std. Dev.	1.1	--
Lead	Mean	7.4	9.6
	Std. Dev.	0.6	--
Nickel	Mean	<2.0	<2.0
	Std. Dev.	0	--
Zinc	Mean	42	38
	Std. Dev.	22	--
Silver	Mean	<0.2	<0.2
	Std. Dev.	0	--
Arsenic	Mean	<0.2	<0.2
	Std. Dev.	0	--
Mercury	Mean	1.63	0.85
	Std. Dev.	0.42	--

NOTE: All heavy metal concentrations are expressed in units of mg/kg dry weight.

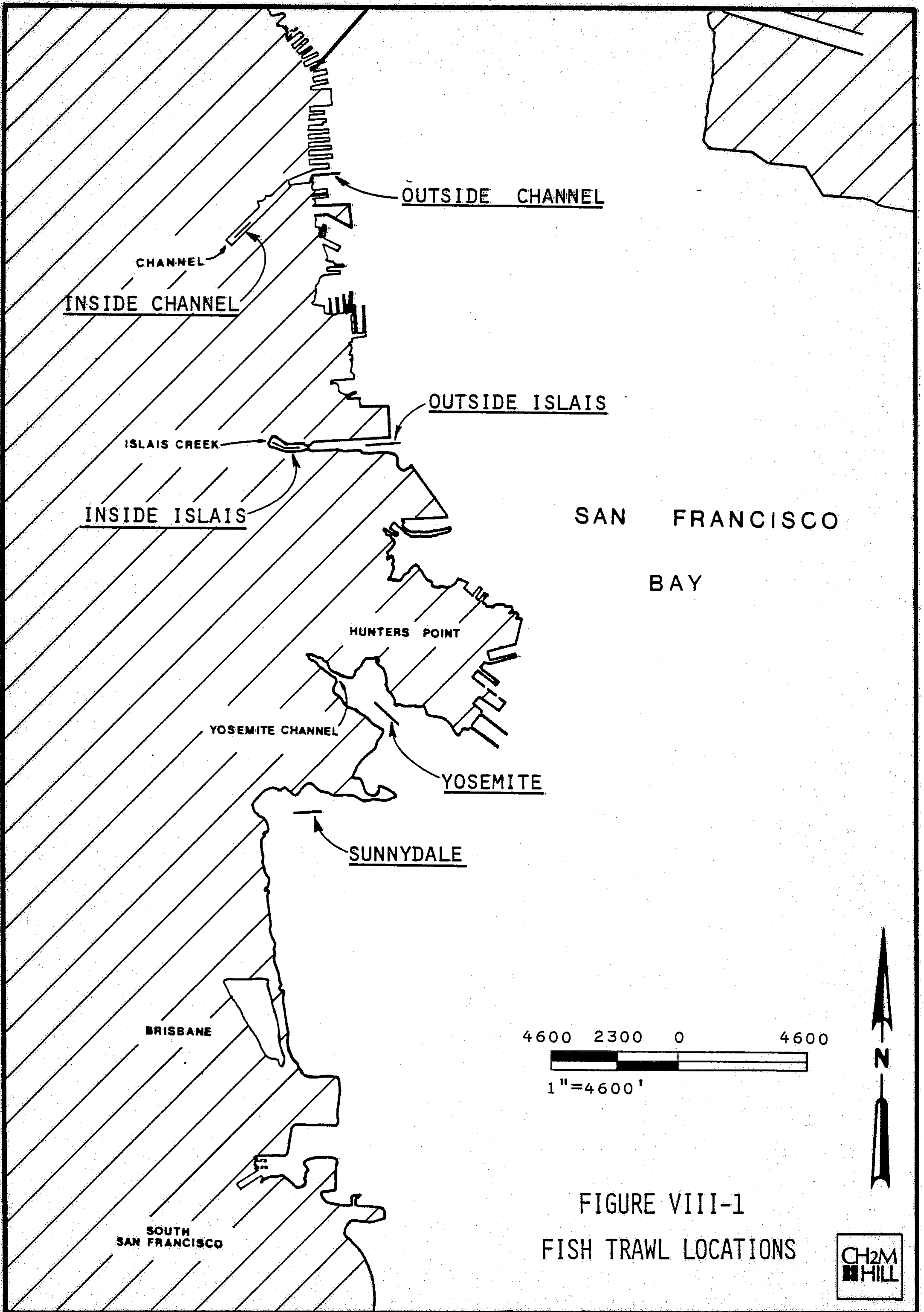
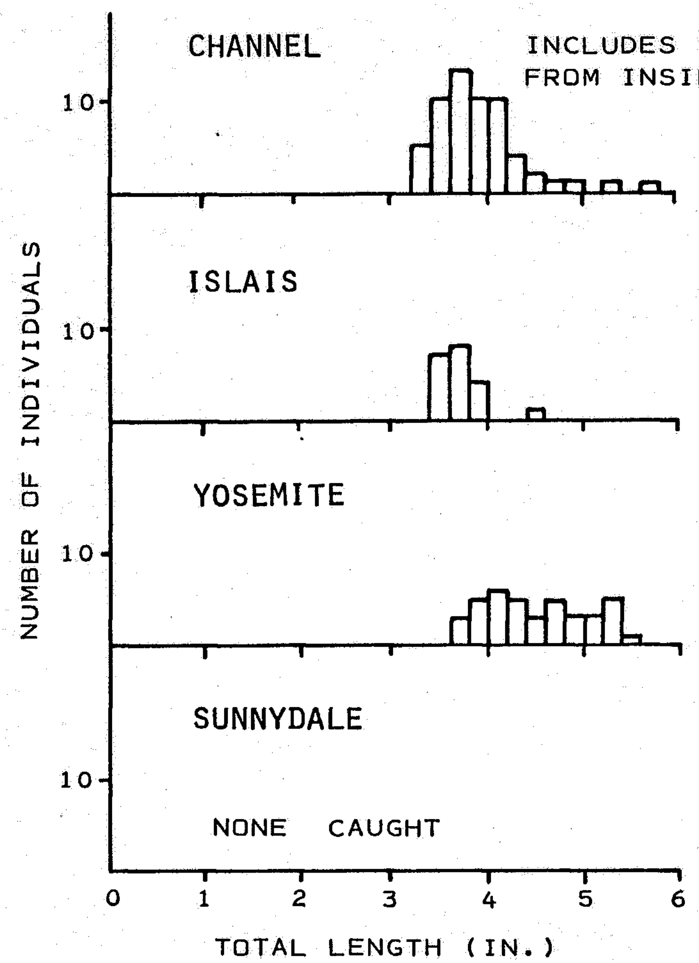
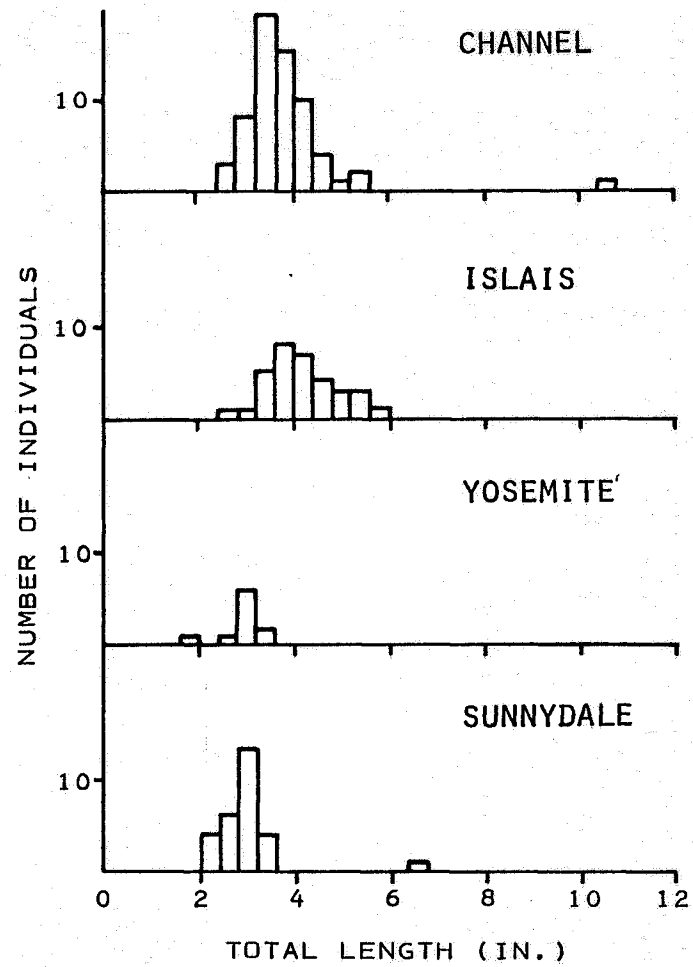


FIGURE VIII-1

FISH TRAWL LOCATIONS



LENGTH FREQUENCY DISTRIBUTIONS
FOR SHINER SURFPERCH



LENGTH FREQUENCY DISTRIBUTIONS
FOR ENGLISH SOLE

FIGURE VIII-2

CH2M HILL

IX. RELOCATION OF COMBINED SEWAGE OVERFLOWS

INTRODUCTION

Future discharge requirements for the combined sewer overflows have not been issued by the San Francisco Bay Regional Water Quality Control Board. Existing regulations prohibit discharge of waste to dead-end sloughs or to any point where it does not receive a minimum initial dilution of 10:1. The discharges from the existing overflow locations (at the head of Channel Street, Islais Creek and Yosemite) do not meet existing discharge requirements. Therefore, relocation of existing combined sewage overflows was investigated to determine the feasibility of meeting the minimum discharge requirement. Two solutions were studied; one was deep water outfalls and the other was shoreline surface discharges. A feasibility study was made to determine the practicality of relocating the existing overflows and the benefits to be obtained from such a relocation. For purposes of this study, CCSF requested that systems capable of achieving a 5:1 and 10:1 initial dilution be investigated.

Four bay discharge locations and overflow capacities were identified by the City and County of San Francisco (CCSF). Table IX-1 summarizes peak flows for each overflow discharge location. These flows represent the "1 hour per year" rate which means that the capacity of the discharge structure will be exceeded 1 hour in an average rainfall year. The four discharge sites are shown on Figure IX-1.

PHYSICAL CHARACTERISTICS IN SAN FRANCISCO BAY

Tides vary from lowest low water (LLW) of -3.0 feet to highest high water (HHW) of 9.0 feet at "Potrero Point." The reference elevation is mean lower low water (MLLW). The tidal differential at the four proposed locations is assumed very small, and the tidal elevations are assumed to be the same at these locations. At the request of CCSF, the outfall capacity calculations were based on mean higher high water (MHHW) of 6.3 feet and the dilution calculations were based on mean lower low water (MLLW).

Previous model tests at the Army Corps of Engineers Bay Model have greatly aided in understanding tidal effects on Bay waters (Refs. 1, 2 and 3). On each ebb tide, flow is directed predominantly west and south away from the Golden Gate. Flood tides pull in water from nearshore areas north and south of the Bay opening. Tidal exchanges and, as a result, flushing capacities increase as the release point approaches the Golden Gate.

Circulation in the San Francisco Bay is a complex regime influenced by tidal volume exchange, Delta outflow, and bottom topography. The net circulation of the South Bay (defined as that portion of the Bay south of the Oakland Bay Bridge) is counterclockwise with the main current centered in the deep water channel on the west side that runs from the Bay Bridge to Redwood City. The major counterclockwise currents occur adjacent to the main channel in the shallow waters of the East Bay and in the West Bay near the airport. There are many smaller eddy currents along the nearshore areas which tend to restrict current movement.

The limited net outflow from the South Bay is indicative of the poor net flushing capacity. This condition is more severe at distances further from the Golden Gate. The net tidal exchange in the extreme South Bay is very sluggish, and pollutants that enter the area tend to stay there.

In general, historical data indicates that the proposed discharge locations are typically stratified during the winter and relatively nonstratified during the summer. Dr. Fischer (Ref. 2) reported that freshwater flows out of the Delta do affect the salinity and hence the density profiles within the Bay. A flow of 100,000 cfs which occurs in most winters changes the salinity regime of the South Bay from the typical summertime, well mixed basin with a uniform salinity of approximately 31 ppt (parts of salts to 1,000 parts of water), to one of a stratified water body with a typical salinity range of 15 ppt at the surface to 25 ppt at the bottom. Data from the USGS sampling stations 21, 22, 23 and 20 were used for the proposed discharge locations 1, 2, 3, and 4 (Ref. 4) due to their nearby locations (see Figure IX-1). Figure IX-2 shows typical density profiles at location 1 (Channel Street). Profiles measured on 27 January 1970 and 21 August 1970 were selected as representing maximum and minimum density stratification. Maximum density stratification is usually defined as the largest difference in density between the surface and the bottom. For convenience, density is often expressed in terms of sigma units which are equivalent to the following formula:

$$(\text{density in } {}^{gm}/_{cc} - 1) \times 1{,}000$$

The maximum stratification in Figure IX-2 shows a difference in density of 15 sigma units. For reasons which will be discussed later, the use of this density profile as the basis for design of the outfall system would be unnecessarily conservative. A density profile measured on 8 February 1973 was selected as the basis for design. Similarly, Figure IX-3 shows typical density profiles at location 2. Profiles measured on 27 January 1970 and 30 April 1970 represent maximum and minimum density stratification. The density profile on 8 February 1973 was selected for the diffuser design.

Figure IX-4 shows typical density profiles at location 3 (Yosemite). The density profile on 8 February 1973 was selected for diffuser design.

Figure IX-5 indicates typical density profiles at location 4 (North Point). The density profile measured on 24 February 1970 was selected as a representative density profile for diffuser design.

Strong and persistent currents are observed at the proposed discharge sites. The currents are dominated by tidal influence with the principal current direction approximately parallel to the shore and pointing towards the Golden Gate (Ref. 5).

Water depths in the vicinity of the specified sites generally range from 25 to 60 feet. Greater depths exist to the west of Yerba Buena Island and to the south of Alcatraz Island. On the basis of existing information there does not appear to be enough advantage from the standpoint of dilution to justify installing the diffusers in the deeper water.

An assessment of the risk of physical damage to an outfall resulting from dredging or ship's anchors was reported by Brown and Caldwell (Ref. 3). Probabilities of damage at five Bay locations were estimated. The least attractive of the five sites with respect to anchor damage was in the vicinity of Islais Creek. The principal consideration given to those potential problems for this study was to extend the Channel Street deepwater outfalls so the diffusers are located in the Northbound (outbound) Traffic Lane. It was felt that damage to diffuser risers from dragging anchors would be less likely there than in the Southbound (inbound) Traffic Lane. Ships will occasionally use anchors for slowing down while entering port but will rarely drop anchor leaving port. Some warning devices would need to be provided along the diffuser line to minimize the potential damage.

DEEP WATER OUTFALLS

A buoyant jet model based on Koh and Fan (Ref. 6) was used to predict the initial dilution. This model assumes that the initial dilution of the discharged effluent is achieved as a result of the interaction of the buoyancy and momentum of the discharge with the ambient ocean. The model predicts behavior of a buoyant jet issuing from a diffuser in stagnant (no current), density stratified surroundings. It also takes into consideration the effects of the interference of the jets from the multiple ports as well as the effect of the finite thickness of the sewage field. To achieve an initial dilution of 10:1 and 5:1 for the combined sewer overflows, under the assumptions of zero current and maximum density stratification, an unreasonably long diffuser would be required. A more reasonable set of physical conditions was selected (zero current and density stratification of 6 sigma units) as design constraints to determine the diffuser characteristics required for satisfying the 10:1 and 5:1 dilution criteria.

Also, the EPA "plume" program was utilized for comparison. The "plume" model can determine the geometric and dynamic behavior of a single buoyant round plume issuing from a port in stagnant, density stratified surroundings. Both the "buoyant jet" model and "plume" model are conservative because they do not account for any increased rate of dilution associated with ambient currents in the region of the discharge. The increased initial dilution due to the effect of currents would be substantial (Ref. 7).

Head available for a gravity outfall discharge is limited by the combined sewer system. Table IX-1 listed the maximum upstream water surface elevation. The Manning formula was used to calculate friction losses in the outfall pipes and diffusers. A maximum "n" of 0.016 was used for the hydraulic calculations. At the request of CCSF, the outfalls were sized to discharge peak flows against the mean higher high water.

Extremely large outfall pipes were required to discharge the peak overflows by gravity with the limited head available. Even with these large pipes, it must be emphasized that outfall capacity will be reduced at tides higher than MHHW. A gravity outfall with a diffuser is not really feasible because the available heads are just too small. The outfall pipe diameter could be reduced if the flows were pumped. Table IX-2 summarizes the diffuser characteristics for each extended deepwater outfall system. Each outfall has two alternatives: one by gravity discharge and another one by pumping. Figure IX-6 shows the layout and profile of the Channel Street outfall configuration (outfall 1A gravity system). Outfall 1A pumping system and outfall 1B (gravity and pumping) have not been shown but are similar. The riser spacing and configuration are similar but not identical to San Francisco's proposed ocean outfall (Ref. 8). A typical riser cap configuration is shown on Figure IX-9. Figures IX-7, IX-8 and IX-9 show the layout and profile of the Islais Creek, Yosemite and Northpoint outfall configuration respectively.

A headworks structure or pumping station should be provided to connect the combined sewer overflow system to the outfall system.

The entrance into the outfall pipe should be below low tide elevation. A separate pump station was provided for each pumping alternative. Table IX-3 shows the pump head and estimated horsepower requirement for each pumping alternative.

The scope of work for this study did not include an analysis of cumulative long-term dilutions. This subject was addressed by Metcalf and Eddy who conducted dye tests with the Corps of Engineer's Bay Model (Ref. 3). The dye tests concluded that: (a) tidal action tends to isolate the Lower and South Bay from North Bay and ocean waters, causing accumulations of pollutants in the Lower and South Bay; (b) circulation in the South Bay intensifies its poor flushing ability and the tendency of nearshore areas to retain waste and (c) dispersion of Bay waters spreads pollutants throughout the South Bay.

Because very strong density stratification exists in the Bay during the wet weather season, the wastewater plume discharged from a deep water diffuser would be submerged most of the time. Tidal action in the Bay would tend to trap a submerged plume. Therefore, the deepwater discharges may have a detrimental water quality impact on the South Bay because the plume would tend to have a net displacement toward the South Bay (rather than the ocean) over several tidal cycles.

Operation and maintenance considerations are an important aspect of an outfall. The following O&M criteria have been considered:

- Port check valve - The locations of the proposed outfalls are inside San Francisco Bay. Very little sand intrusion into the diffuser is expected. A single one-way flapper port valve will be provided for the outfall diffuser system.

- Antifouling materials - Construct all parts of the valves and line the riser cap and ports with antifouling materials such as no-foul rubber or 90-10 copper nickel. This will help prevent problems associated with organisms attaching themselves to outfall ports and valves.

- Manholes and end structures - The manholes and end structures will be similar to those proposed for San Francisco's ocean outfall to provide access for maintenance (Ref. 9).

- Port elevation above the seabed - Due to the instability of the Bay mud, the ports will be placed at least 5 feet above the seabed. The riser cap will be removable.

- Flushing - A flushing system is considered unnecessary at this time because sand intrusion has not been identified as a serious problem.

Feasibility level construction cost estimates for the deep water outfall alternatives are summarized on Table IX-4. These costs are subject to the following qualifications:

- Costs were based on March 1979 dollar value. They were not escalated for future inflation, and therefore do not reflect the actual cost of labor, materials and equipment at the future time of construction.

- Total estimated costs excluded the expense of site investigation, contract administration, inspection, construction management, permits, and financing fees.

- Interference, if any, with existing structures and pipelines was not considered.

- Interfaces with onshore facilities were not included. Cofferdams, sheet piling, etc., associated with the headworks and transition structures were assumed to be done by others.

- Excavation quantities were based on 2-1/2:1 side slopes in sand at North Point and on 1-1/2:1 side slopes in Bay mud elsewhere. Disposal was assumed to be by barge dumping at an approved site near Alcatraz Island.

- Redredging, overdredging and extra dredging were allowed for by factoring theoretical quantities.

- Pipe was assumed to be reinforced concrete with a maximum section length of 24 feet and not exceeding 100 tons in weight per section.

- All pipe was assumed to be placed from a crane barge with the rate of installation based on considerations of weight and size of sections, depth of water and interference with ship traffic.

Table IX-4 also indicates estimated construction costs for the various pump stations. The pump station cost estimates included a simple superstructure to house pumps, engines and other equipment and a pump wet well. The pump station costs did not include equipment replacement costs during the design life cycle nor the annual operation and maintenance costs.

SHORELINE SURFACE DISCHARGES

Relocation of existing overflows from Channel and Islais to a Bay surface discharges would improve water quality marginally. Shoreline surface discharges can meet a 5:1 initial dilution requirement if the discharge velocity can be maintained at 7 fps or more and will meet the 10:1 dilution requirement if the discharge has velocities exceeding 10 fps. Table IX-5 shows the initial dilution achievable by a shoreline surface discharge. The initial dilution calculations are based on SWRCB staff guidelines for implementation of Table B in the Ocean plan, dated 15 January 1979.

Dye tests during this study indicated that a portion of a surface discharge at the mouth of Channel Street would be carried back into its dead end sloughs. Discharge at the pierline of Islais Creek would not likely return to the dead end slough. However, the shoreline surface discharges would improve water quality in sloughs during the period immediately after an overflow event. Table IX-6 presents the advantages and disadvantages of relocating overflows to the Bay shoreline. In general, relocating overflow discharges to the shoreline would marginally improve a transient water quality problem in the sloughs. A relocated surface discharge could meet the dilution discharge requirement if high velocities can be maintained.

During stratified conditions in wet weather, the surface waters are rapidly flushed out of the Bay whereas the waters below the pycnocline will actually tend to be drawn back into the South Bay over several tidal cycles. Therefore to limit overall impacts of overflow on Bay water quality, the discharges should be into surface waters rather than through deep outfalls, where the effluent would be trapped in the inward-moving lower (saltier) layer. Even though the initial dilution might be higher and immediate shoreline impact less, nevertheless the overall detrimental impact of a deepwater outfall is predicted to be considerably greater. Because the stratification is intense, the only feasible way to get the wastewater into the surface layer is by a shoreline discharge (Ref. 10).

For the purpose of surface water discharge at the shoreline, there is no water quality advantage to collecting all the wastewater overflows to just a few places except for convenience of system operation and control. A larger number of shoreline discharges (like a shoreline diffuser) will give higher initial dilutions and less long-term impacts (Ref. 10). Dr. Brooks also indicated that an overflow in the northern area of the City will have less impact due to better flushing characteristics.

The total cost of relocating the overflows to the Bay shoreline was estimated by CCSF at $100 million.

SUMMARY

The discharge requirements of 10:1 or 5:1 dilution can be met with a deepwater outfall or a Bay shoreline surface discharge.

With a deepwater outfall, the wastewater plume will be submerged and would have a greater probability of becoming trapped in the South Bay due to the overall poor net flushing capacity. The negative water quality impacts to the South Bay, the complicated operation and maintenance considerations, and the high construction costs make the extended deep water outfall solution unfeasible.

Relocation of existing overflow discharges to the Bay shoreline would improve the water quality in sloughs marginally. The dilution requirements could be met if high discharge velocities are provided. The shoreline surface discharges would create some negative water quality impacts around the discharge locations and nearby shorelines, but this impact would be transient and would be rapidly flushed out of the Bay by tidal flushing. A portion of the shoreline discharge would be carried into Mission Creek (Channel) by tidal action. Water quality impacts due to the CSO's would be less intense (in comparison to existing conditions) inside the dead end sloughs but the impacts would extend over a greater portion of the Bay. Again, the high construction cost of this option in comparison to the benefits obtained make this solution unattractive.

References

1. Brown and Caldwell, Inc., "Predesign Report on Marine Waste Disposal," Volumes IV and V, 1971, for the City and County of San Francisco.

2. Fischer, Hugo B. and Waterfront Design Associates, "The Effects of Delta Outflow on Density Stratification in San Francisco Bay for ABAG," June 1977.

3. Brown and Caldwell, "Evaluation of Bay and Ocean Discharge of Bayside Dry Weather Effluent from the City and County of San Francisco," September 1977.

4. Smith, Richard E., U.S. Geological Survey, "Water Quality Investigation in the San Francisco Bay," 1977.

5. Tidal Current Charts at San Francisco Bay, U.S. Department of Commerce, National Ocean Survey, July 1973.

6. Koh, Robert C.Y. and L.N. Fan, "Mathematical Models for the Prediction of Temperature Distributions Resulting from the Discharge of Heated Water into Large Bodies for Water," EPA, October 1970.

7. Roberts, P.J.W., "Dispersion of Buoyant Wastewater Discharge from Outfall Diffusers of Finite Length," Report No. KH-R-35, W.M. Keck Laboratory of Hydraulics and Water Resources, California Institute of Technology, Pasadena, California, 1977.

8. CH2M HILL, Southwest Ocean Outfall Project, "Sanitary and Hydraulic Status Report," December 1978.

9. CH2M HILL, Southwest Ocean Outfall project, "Sanitary and Hydraulic Status Report," Supplement No. 1, Volumes 1 and 2, April 1978.

10. Dr. Norman H. Brooks, personal communication.

Table IX-1

OVERFLOW CAPACITIES AND MAXIMUM UPSTREAM WATER SURFACE ELEVATIONS[1]

	Location	Design Capacity Q, cfs[2]	Maximum Upstream W.S. Elevation (Feet Above MLLW)
1.	Channel St. Overflow	2,300	11.6
2.	Islais Creek	2,000	10.8
3.	Yosemite Creek	500	12.6
4.	Northpoint	300	11.6

NOTES:

1. Information supplied by the City and County of San Francisco.
2. Estimated 1-year peak hour overflow rate.

Table IX-2

CHARACTERISTICS OF BAY OUTFALL ALTERNATIVES

Outfall Location	Initial Dilution Requirement	Outfall Number	Flow (cfs)	Outfall System	Outfall Diameter (ft)	Outfall Length (ft)	Diffuser Length (ft)	No. of Risers	Riser Spacing (ft)	Port/ Riser	No. of Ports	Riser Diameter (in)	Port Diameter (in)	Water Depth at Diffuser (ft)	Remarks
Channel Street	10:1	1A	2,300	G	18.0	7,460	1,560	26	60	4	104	36.0	16.0	57'-60'	Note 4
					18.0	7,460	1,560	26	60	4	104	36.0	16.0		
				P	17.0	8,920	3,120	52	60	4	208	30.0	13.0		
	5:1	1B	2,300	G	18.0	6,380	480	16	30	2	32	48.0	29.0	57'-60'	Note 4
					18.0	6,380	480	16	30	2	32	48.0	29.0		
				P	17.0	6,760	960	32	30	2	64	36.0	22.5		
Islais Creek	10:1	2A	2,000	G	17.0	2,800	1,560	26	60	4	104	36.0	14.50	30'-34'	Note 4
					17.0	2,800	1,560	26	60	4	104	36.0	14.50		
				P	16.0	4,200	3,120	52	60	4	208	30.0	14.75	30'-40'	
	5:1	2B	2,000	G	17.0	1,780	480	16	30	2	32	45.0	27.0	30'-32'	Note 4
					17.0	1,780	480	16	30	2	32	45.0	27.0		
				P	16.0	2,160	960	32	30	2	64	36.0	22.0		
Yosemite	10:1	3A	500	G	11.25	6,060	960	16	60	4	64	30.0	12.5	27'-30'	
				P	8.0	6,060	960	16	60	4	64	24.0	11.0		
	5:1	3B	500	G	11.25	5,400	300	10	30	2	20	39.0	24.0	27'-30'	
				P	8.0	5,400	300	10	30	2	20	30.0	19.5		
North-point	10:1	4A	300	G	8.75	1,760	360	12	30	2	24	27.0	17.5	42'-52'	
				P	6.25	1,760	360	12	30	2	24	24.0	14.0		
	5:1	4B	300	G	8.75	1,520	120	8	15	1	8	36.0	30.0	42'-48'	
				P	6.25	1,520	120	8	15	1	8	30.0	24.0		

NOTES:
1. G = gravity system; P = pump station
2. Outfall length <u>includes</u> diffuser length.
3. The diffuser length is calculated with zero current and high density stratification.
4. The system has two pipes and "Y" shape diffuser.
5. Water depth is based on MLLW.

Table IX-3

BAY OUTFALL PUMPING ALTERNATIVES

Outfall Location	Outfall Number	Flow (cfs)	Head (ft)	Required Horsepower	Commercial Horsepower
Channel Street	1A-P	2,300	20.8	6,831	7,000
	1B-P		20.8	6,831	7,000
Islais Creek	2A-P	2,000	10.3	2,943	3,000
	2B-P		8.3	2,370	2,500
Yosemite	3A-P	500	32.5	2,321	2,500
	3B-P		28.8	2,057	2,200
Northpoint	4A-P	300	16.9	723	750
	4B-P		16.7	720	750

NOTES:

1. Assume pump efficiency = 80 percent.
2. Assume axial flow, wet pit, vertical pumps are used.
3. Assume diesel engine drive with right angle gear.

Table IX-4

CAPITAL COST ESTIMATES*

			Estimated Construction Cost ($ Millions)				
Outfall Location	Outfall Number	System	Outfall Pipe System	Pump Station	Subtotal	35% Engineering, Legal and Contingency	Total Cost
Channel St.	1A-G	Gravity	44.1	---	44.1	15.4	59.5
	1A-P	Pumping	27.3	7.0	34.3	12.0	46.3
	1B-G	Gravity	39.3	---	39.3	13.7	53.0
	1B-P	Pumping	22.7	7.0	29.7	10.4	40.1
Islais Creek	2A-G	Gravity	19.1	---	19.1	6.7	25.8
	2A-P	Pumping	12.4	3.0	15.4	5.4	20.8
	2B-G	Gravity	14.9	---	14.9	5.2	20.1
	2B-P	Pumping	9.4	2.5	11.9	4.2	16.1
Yosemite	3A-G	Gravity	12.8	---	12.8	4.5	17.3
	3A-P	Pumping	9.1	2.5	11.6	4.1	15.7
	3B-G	Gravity	11.8	---	11.8	4.1	15.9
	3B-P	Pumping	9.1	2.2	11.3	4.0	15.3
North-point	4A-G	Gravity	3.6	---	3.6	1.3	4.9
	4A-P	Pumping	3.0	0.7	3.7	1.3	5.0
	4B-G	Gravity	3.2	---	3.2	1.1	4.3
	4B-P	Pumping	2.7	0.7	3.4	1.2	4.6

*Does not include onshore headworks or transport system, ENR=3597.

Table IX-5

INITIAL DILUTION OBTAINED BY SHORELINE SURFACE DISCHARGE

Location	Flow, cfs	Discharge Velocity, fps			
		10.0	7.0	6.0	3.0
Channel Street	2,300	7.7	5.0	4.2	2.2
Islais Creek	2,000	8.0	5.2	4.4	2.2
Yosemite Creek	500	11.2	7.2	6.0	2.8
Northpoint	300	12.7	8.2	6.8	3.1

NOTES:

1. Initial dilution calculations are based on SWRCB Staff Guidelines for Implementation of Table B in the Ocean Plan, dated 15 January 1979.

2. The dilution, S, used in this table is defined as:

$$S = \frac{\text{Total Volume of a Sample}}{\text{Volume of Effluent Contained in the Sample}}$$

   The SWRCB defined the dilution, D, as:

$$D = \frac{\text{Seawater Flow Entrained}}{\text{Initial Wastewater Flow}}$$

   By definition, D=S-1

3. All surface discharge is assumed the existing overflow structure is relocated at the mouth of the slough.

Table IX-6

ADVANTAGES AND DISADVANTAGES OF RELOCATING OVERFLOW DISCHARGES

Evaluation Factors	Bay Shoreline Surface Discharges	Continue Existing Deadend Slough Discharges
o Discharge Requirement		
10:1 dilution 5:1 dilution	Can meet by controlling discharge velocity.	Cannot meet.
o Water Quality	Transient water quality impacts in Bay	Transient water quality impacts in sloughs
o Solids Deposition	Some solids deposition in Bay. There will be a minimal amount of solids in the overflows when the storage and transport elements are completed.	Some solids deposition in sloughs. There will be a minimal amount of solids in the overflows when the storage and transport elements are completed.
o Cost	CCSF estimated it would cost about $100 million to relocate all Bayside overflows.	No cost.

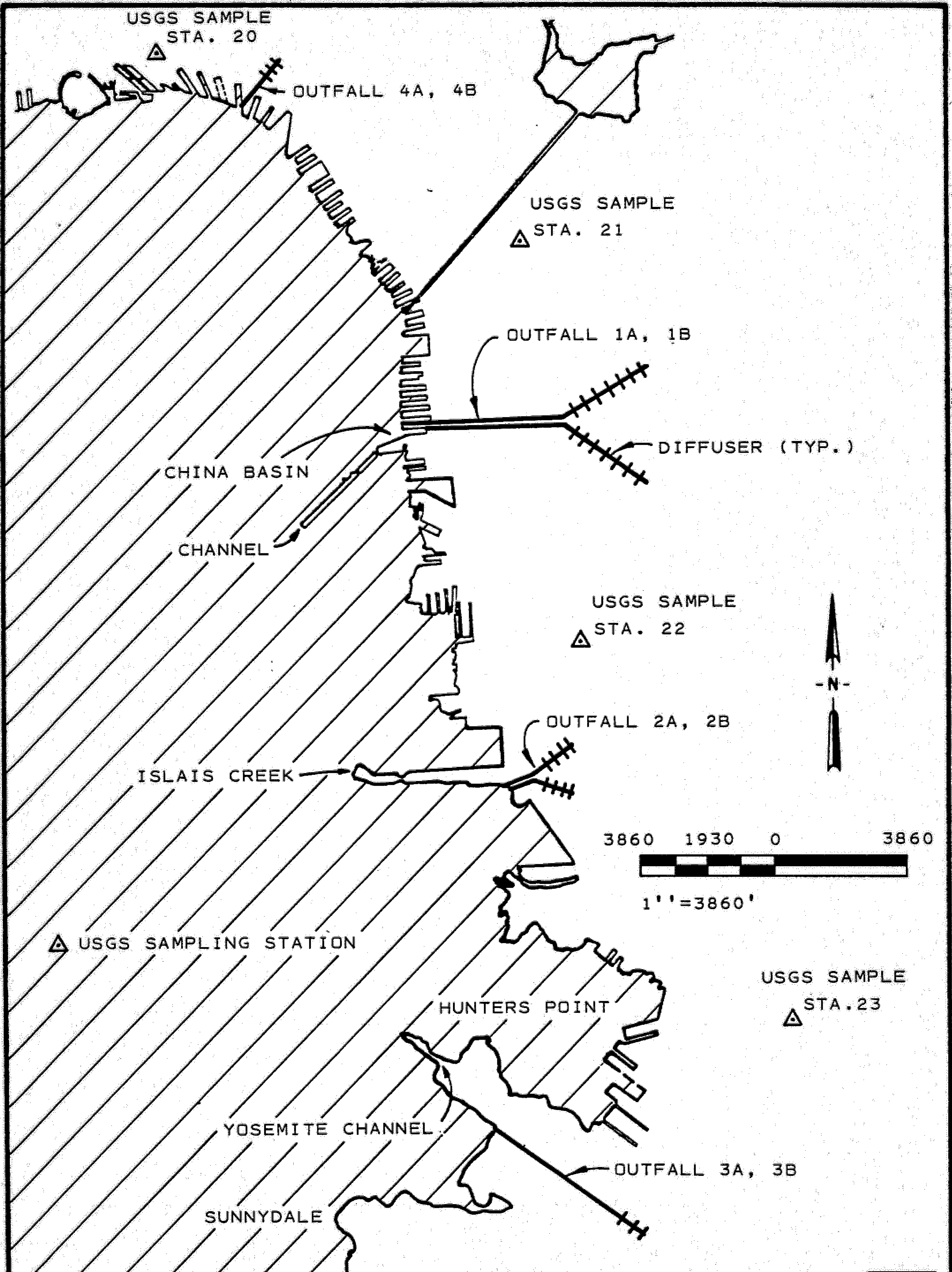


FIGURE IX-1
BAY OUTFALL ALTERNATIVES LOCATION

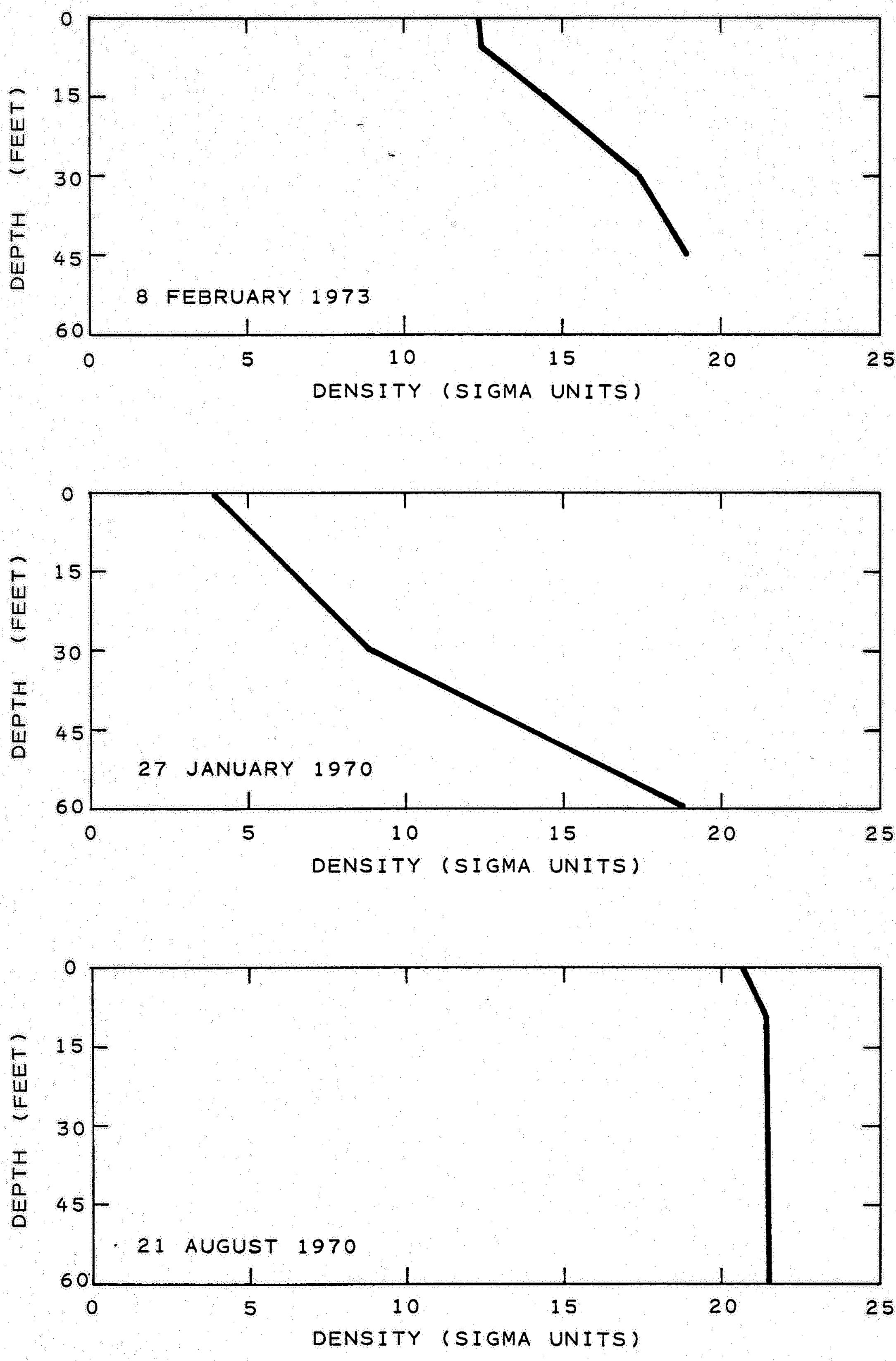


FIGURE IX-2

DENSITY PROFILE

BAY OUTFALL LOCATION 1 (CHANNEL STREET)

CH2M HILL

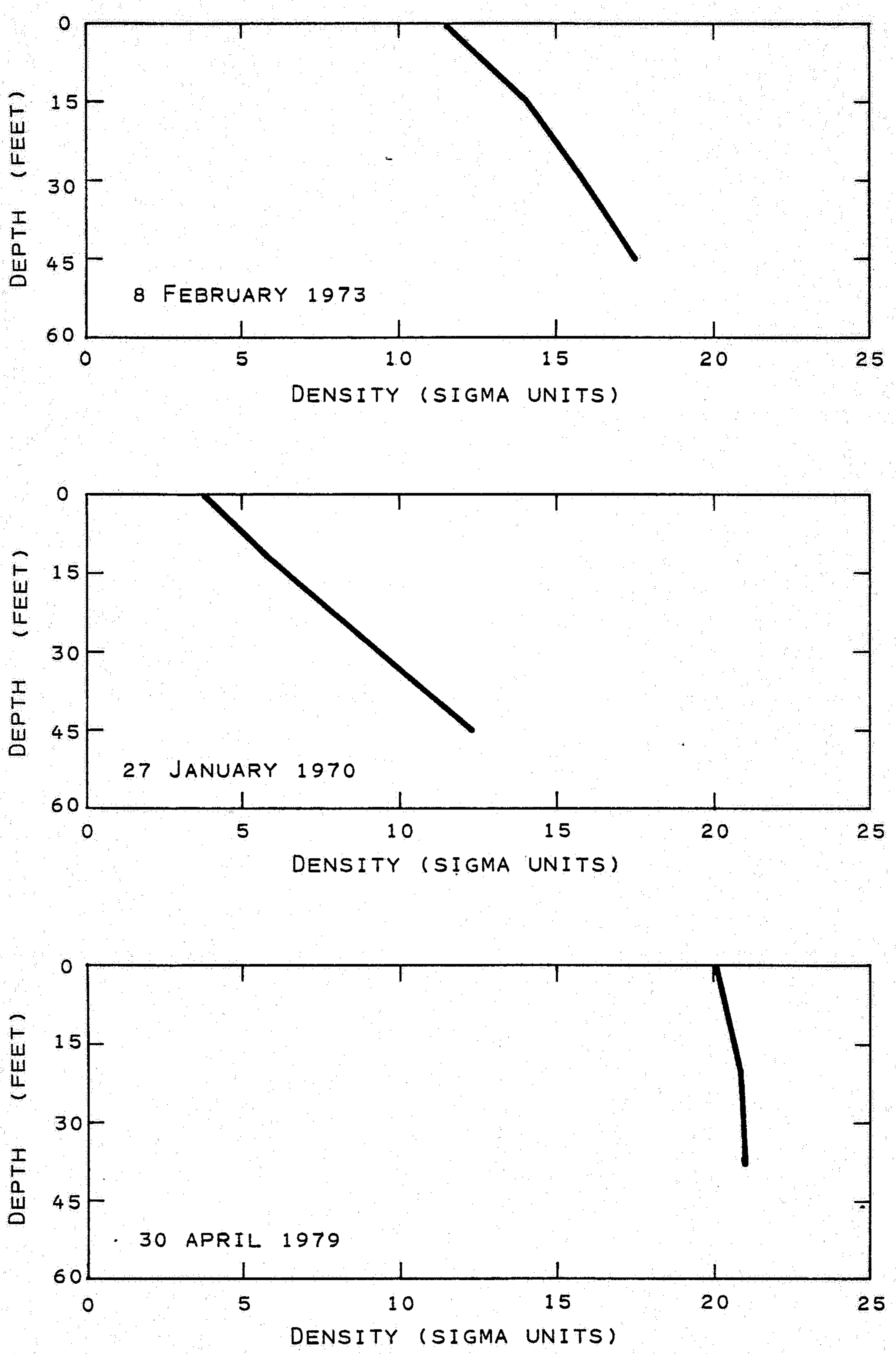


FIGURE IX-3

DENSITY PROFILE

BAY OUTFALL LOCATION 2 (ISLAIS CREEK)

CH2M HILL

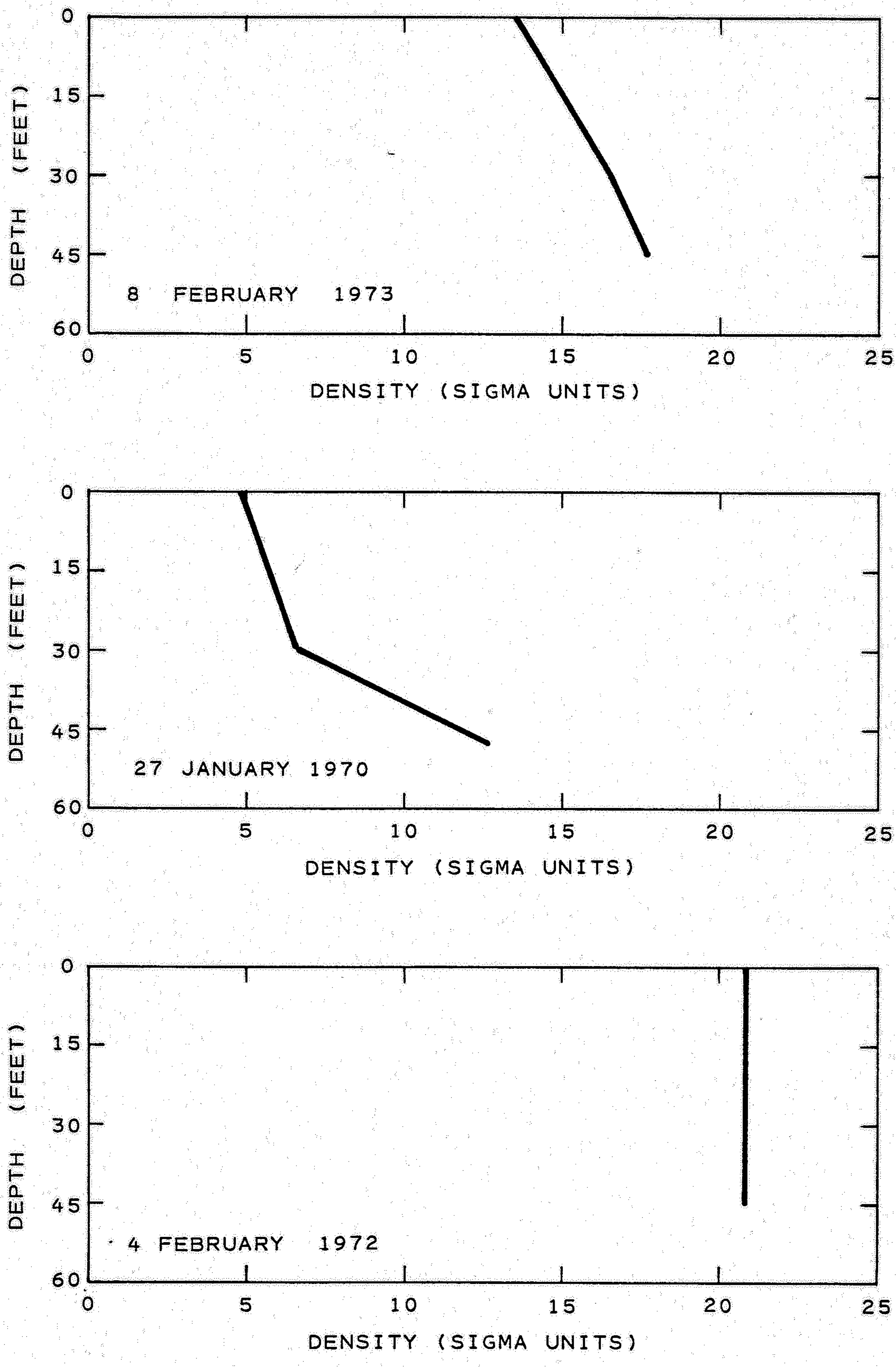


FIGURE IX-4

DENSITY PROFILE

BAY OUTFALL LOCATION 3 (YOSEMITE)

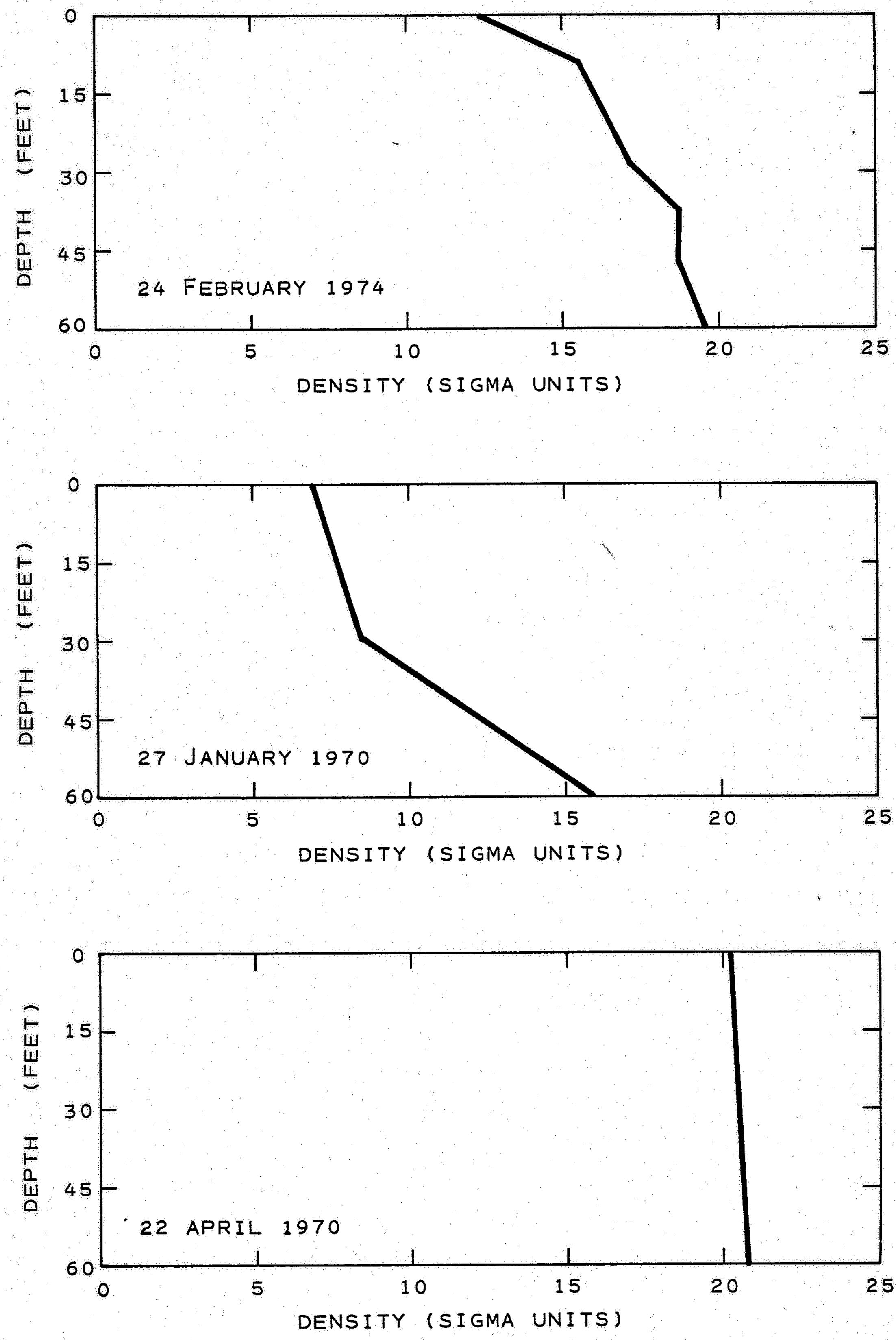


FIGURE IX-5

DENSITY PROFILE

BAY OUTFALL LOCATION 4 (NORTH POINT)

CH2M HILL

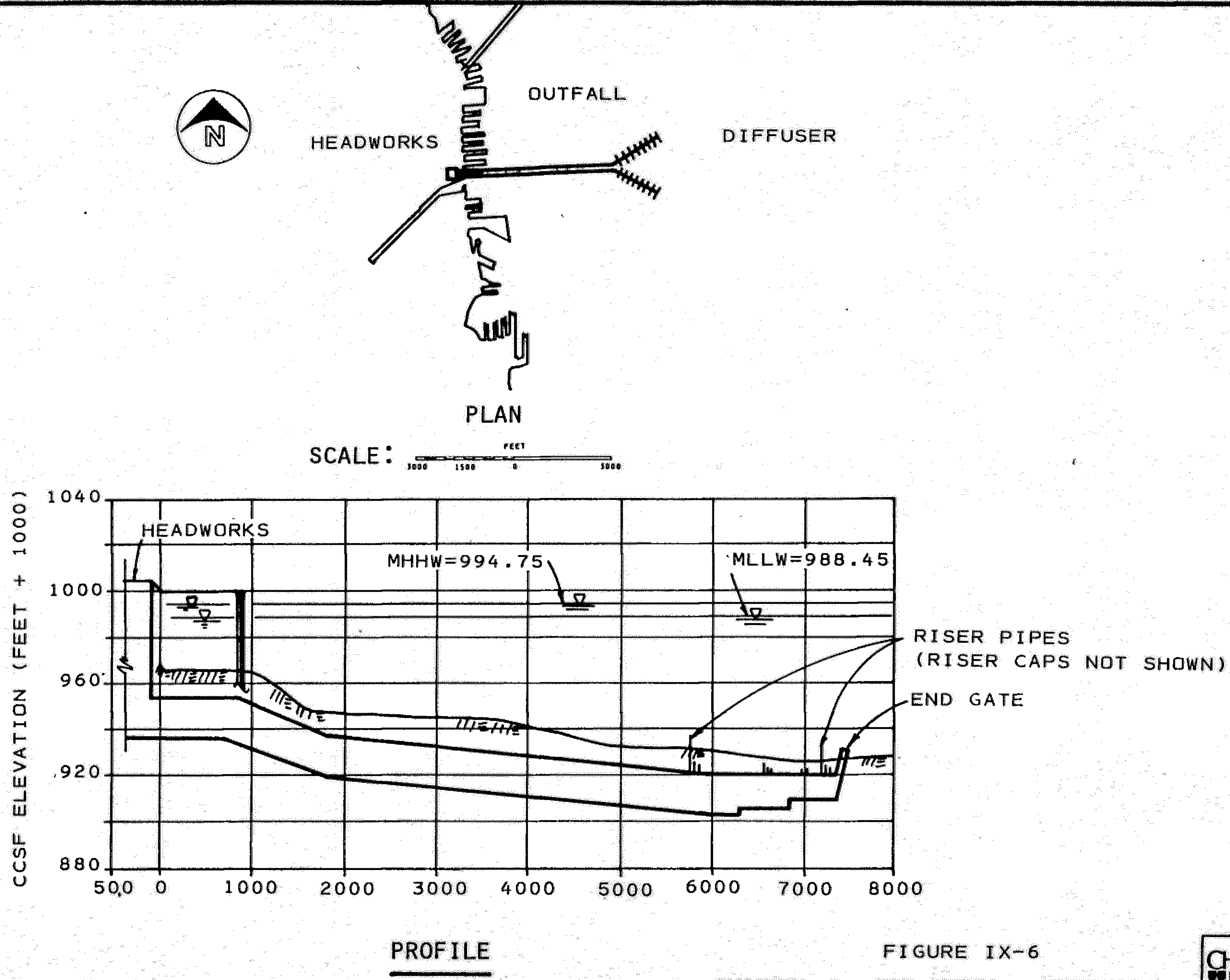
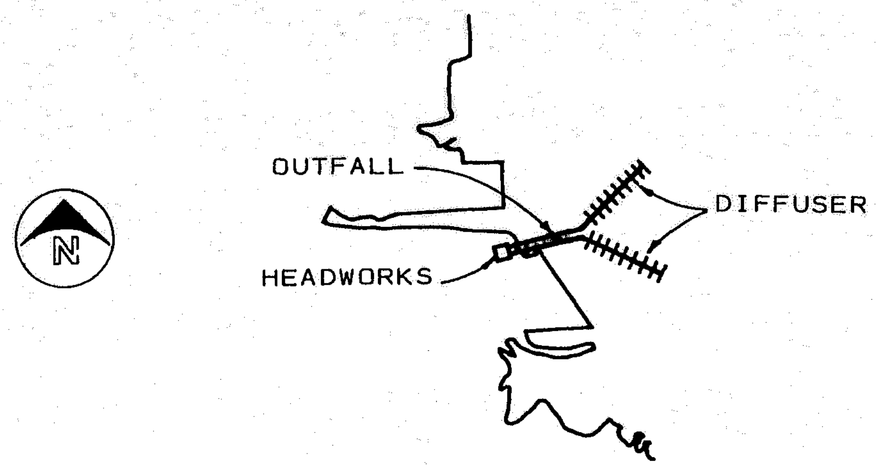


FIGURE IX-6

CHANNEL STREET OUTFALL EXTENSION

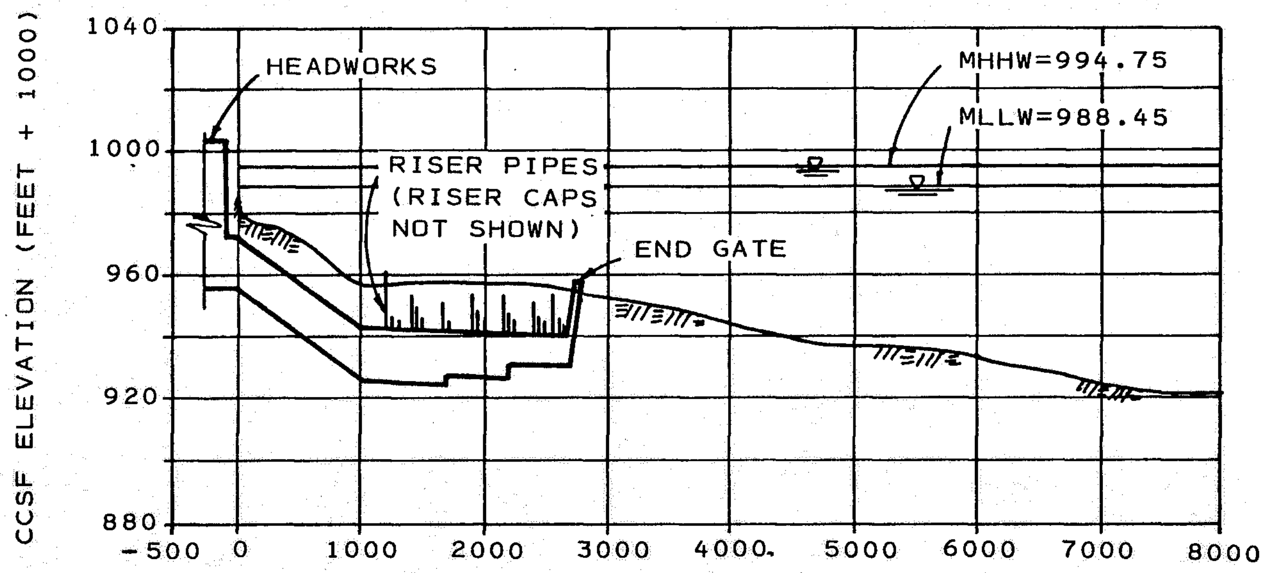
CH2M HILL

F12460.B0



PLAN

SCALE:



PROFILE

FIGURE IX-7

ISLAIS CREEK OUTFALL EXTENSION

CH2M HILL

F12460.B0

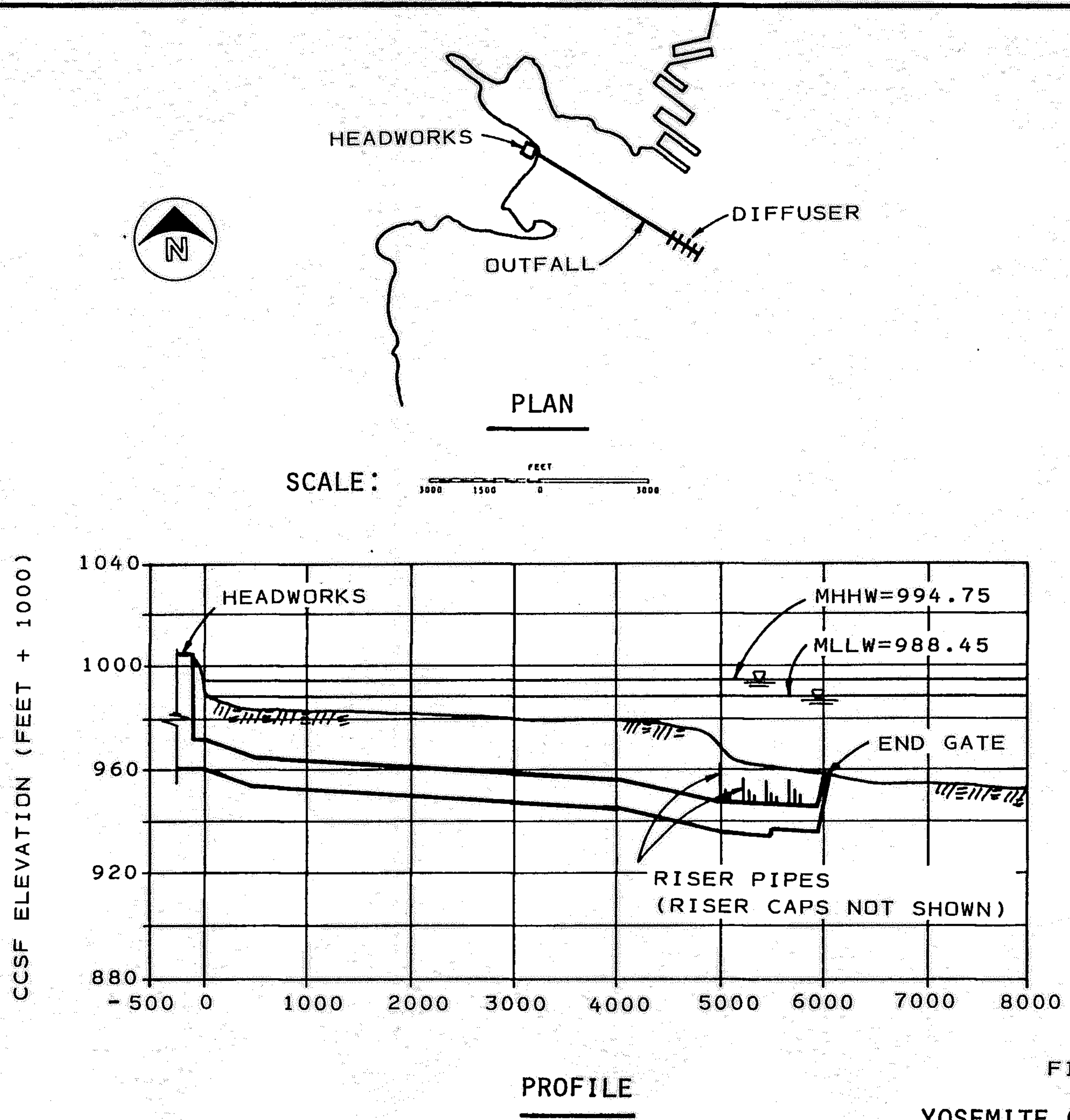


FIGURE IX-8

YOSEMITE OUTFALL EXTENSION

CH2M HILL

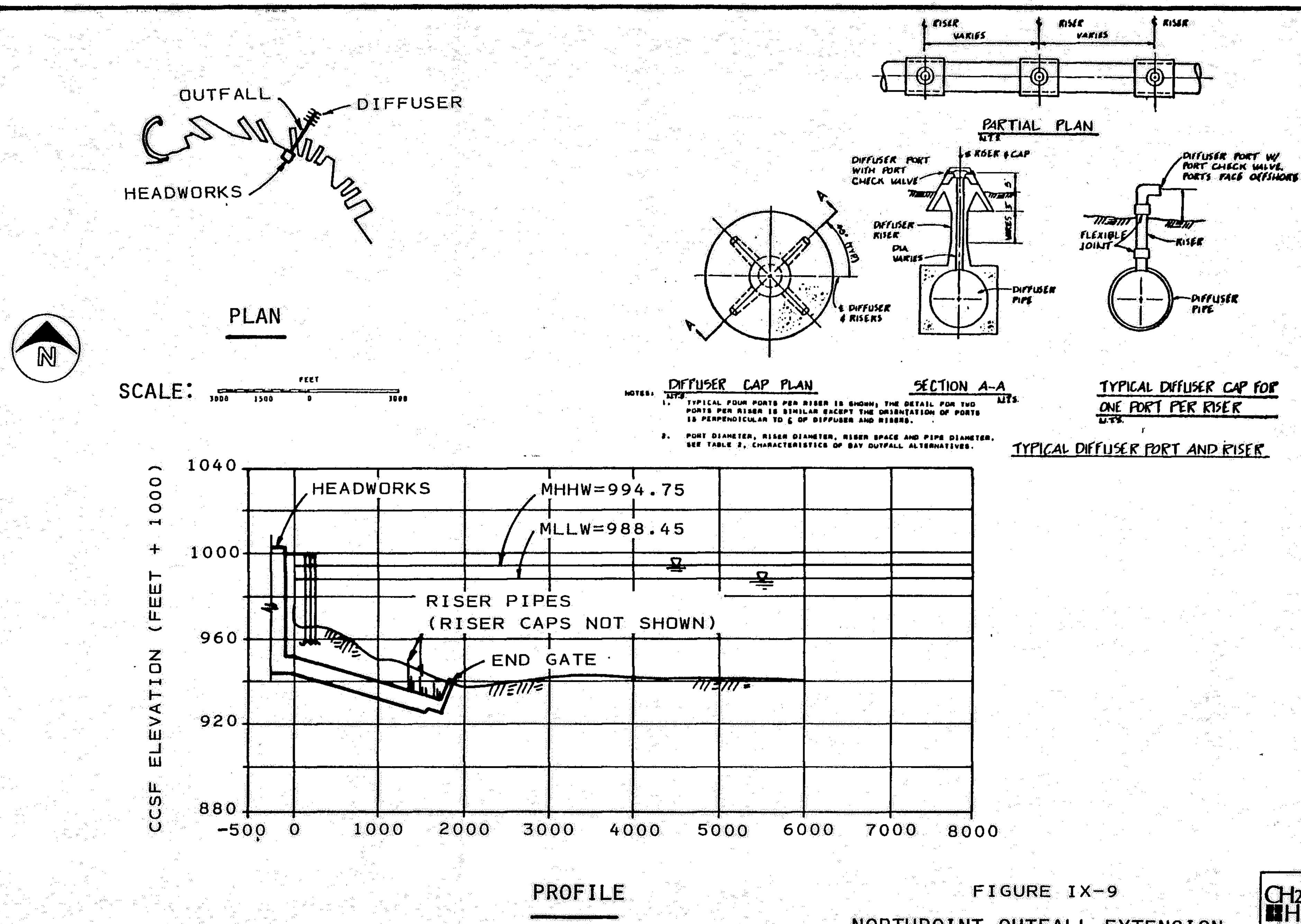


FIGURE IX-9

NORTHPOINT OUTFALL EXTENSION

CH2M HILL

F12460.BO